

PROCESSING AND PROPERTIES OF DIAMOND DISPERSED METAL MATRIX COMPOSITES  
BY POWDER METALLURGY METHODS

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*to the*

DEPARTMENT OF MATERIALS AND METALLURGICAL ENGINEERING  
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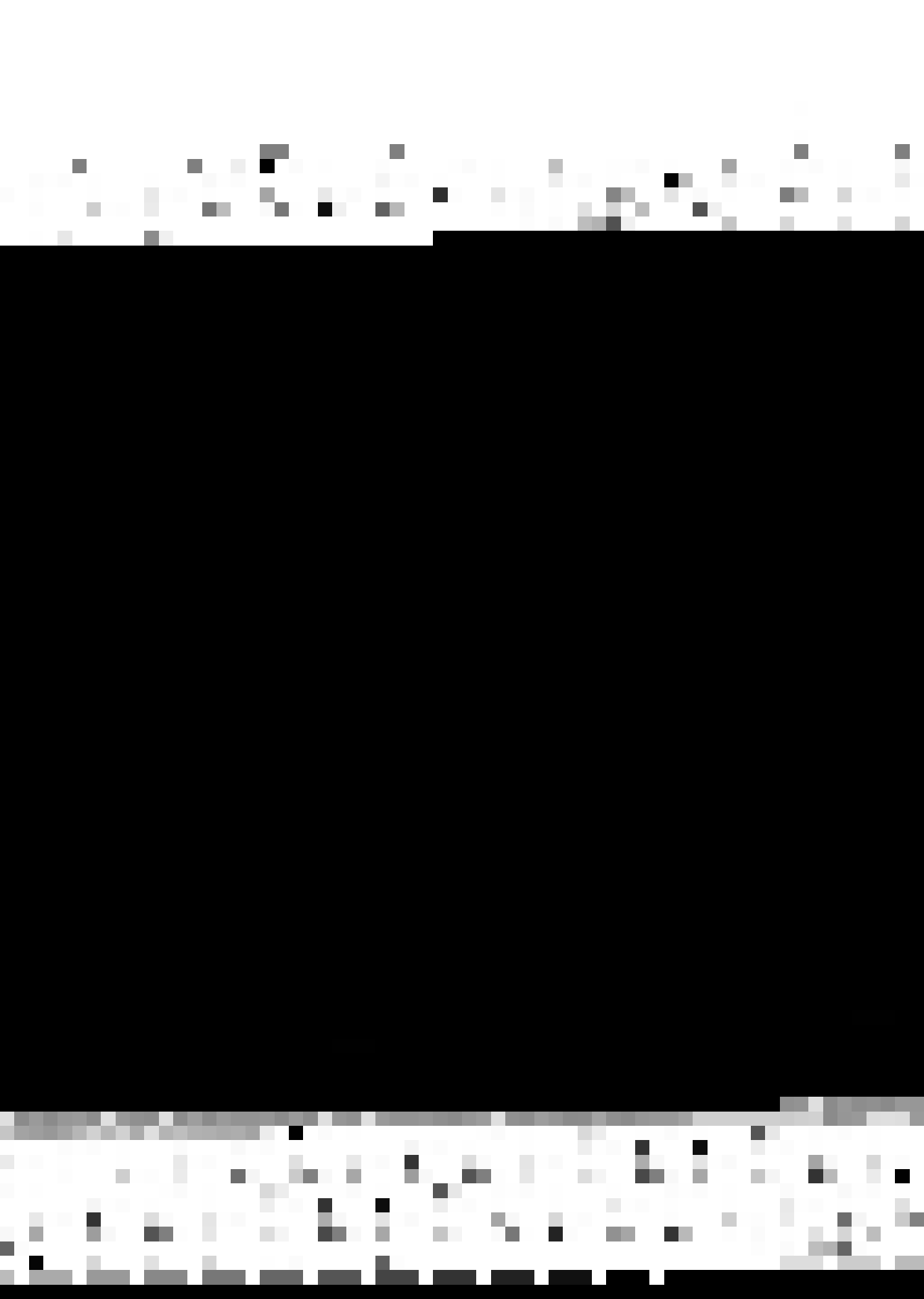
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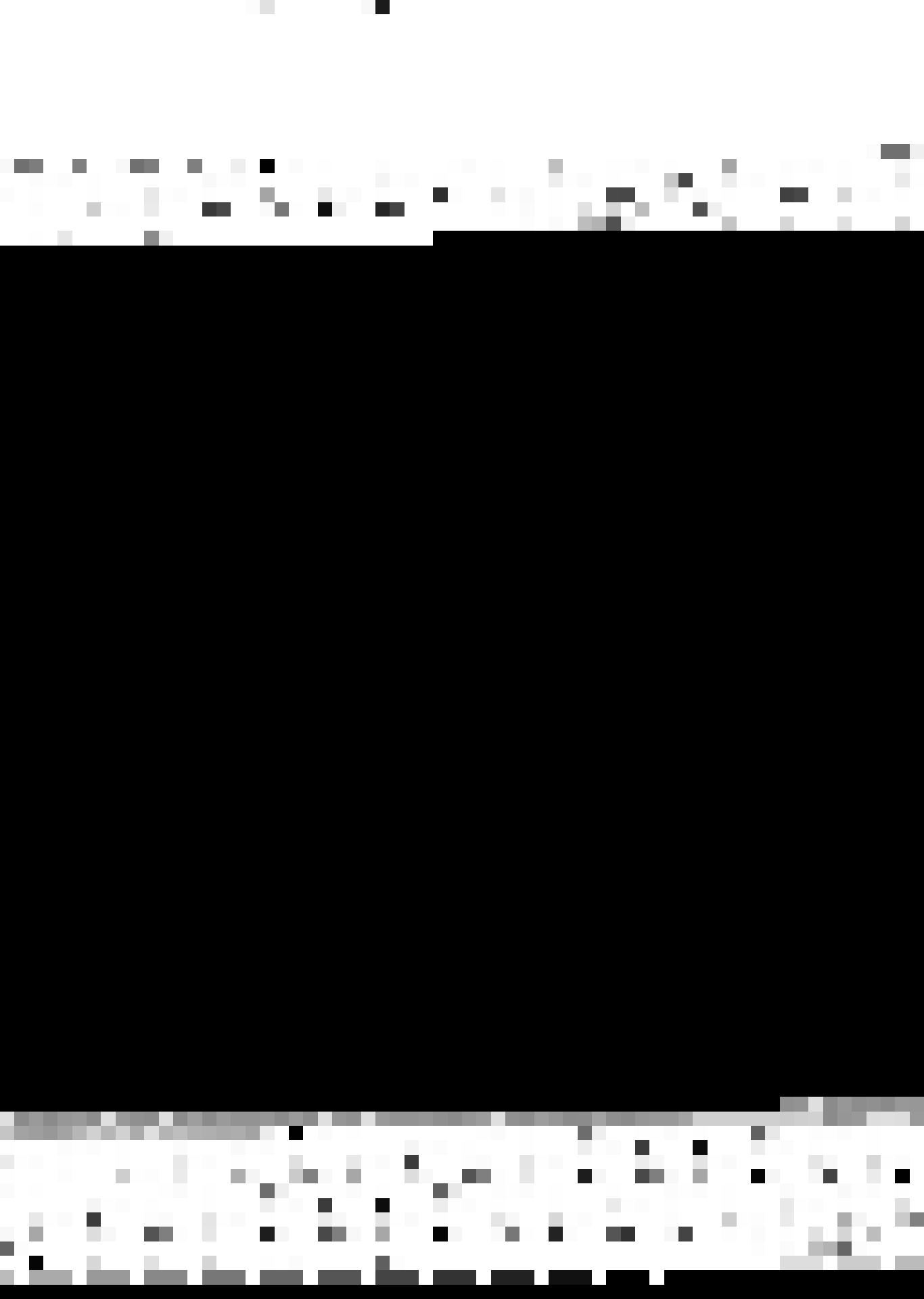


In recent years rolling of mixture of metal and diamond powders has begun to be used as a method of producing diamond tools of small thickness. Diamond containing sheet materials are made in the range of thickness from 20 to 110  $\mu\text{m}$ . It has been established that the rolling of metal and diamond powders with diamond to bronze ratio of 0.5:1, 1:1, 1.5:1 is a reliable method of forming diamond abrasive tools with a large working surface and relatively small thickness. Processing steps can be either, (a) Compacting - sintering - hot rolling, (b) Hot pressing - hot rolling. Better results were obtained when second alternative was followed. The strength of the matrix to which diamond particles are bonded could be increased by the addition of Ni and Ti. Rolling of diamond dispersed bronze composite material was easier when Ni (4 wt%) was incorporated in the bronze matrix. Best wear resistance was observed for the composite material to which both Ni (4 wt%) and Ti (10 wt%) were incorporated. Use of diamond abrasive discs rolled from powders increases the efficiency of glass grinding. These tools can be used to cut thin slice of materials e.g: silicon and stabilised zirconia which are most prospective highly heat resisting structural materials of future. Important application also lies in the field of grinding of ceramics.

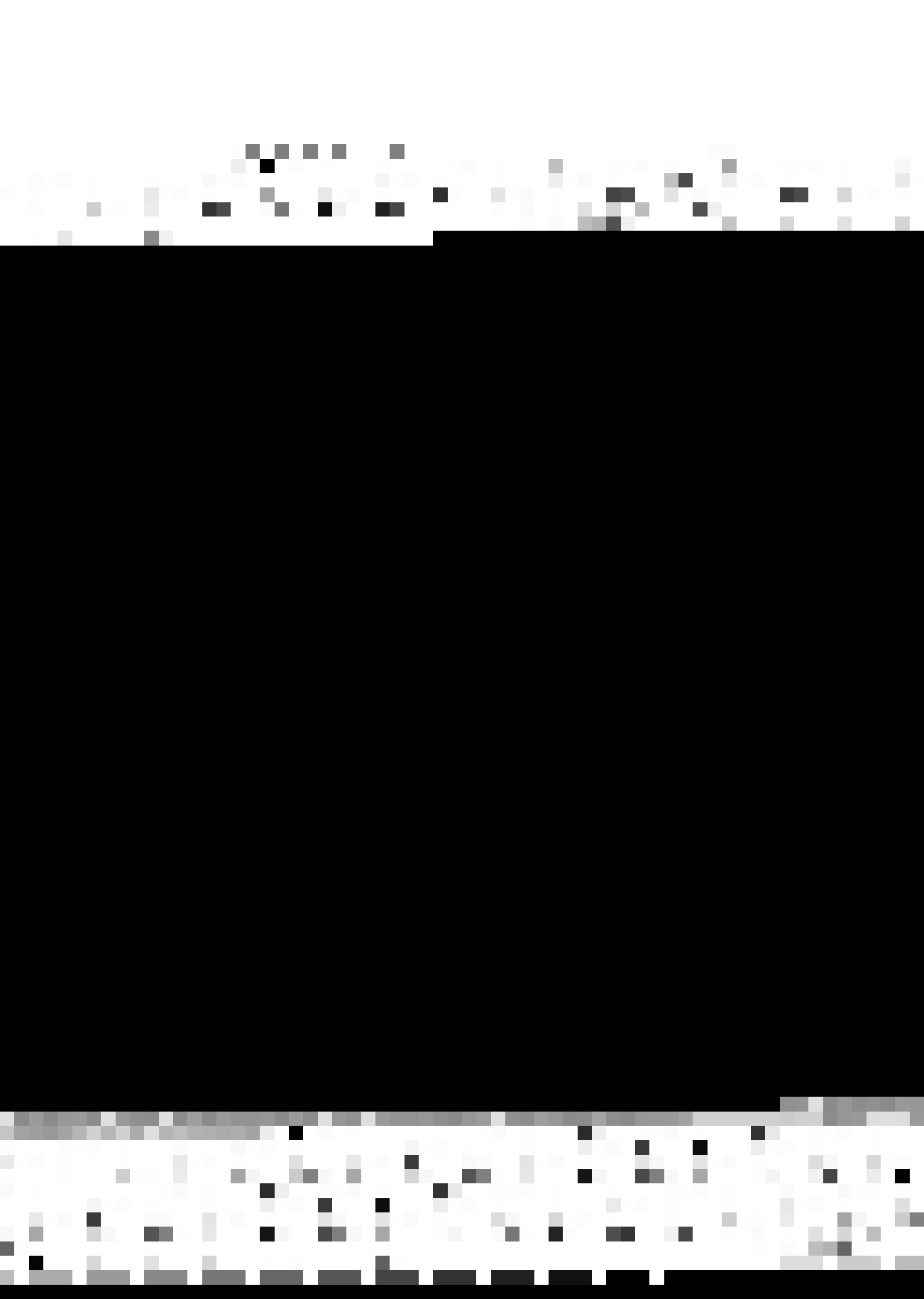


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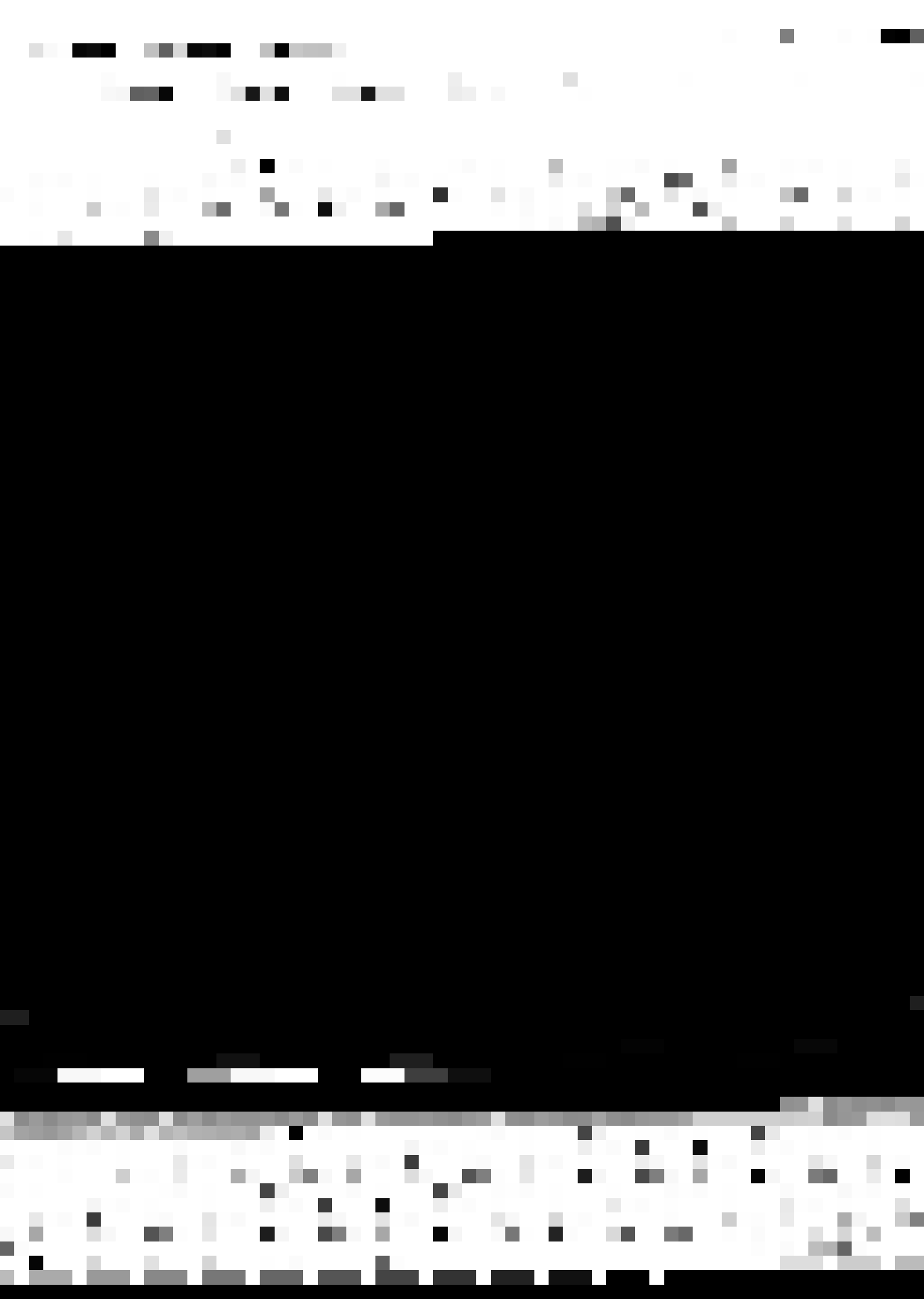




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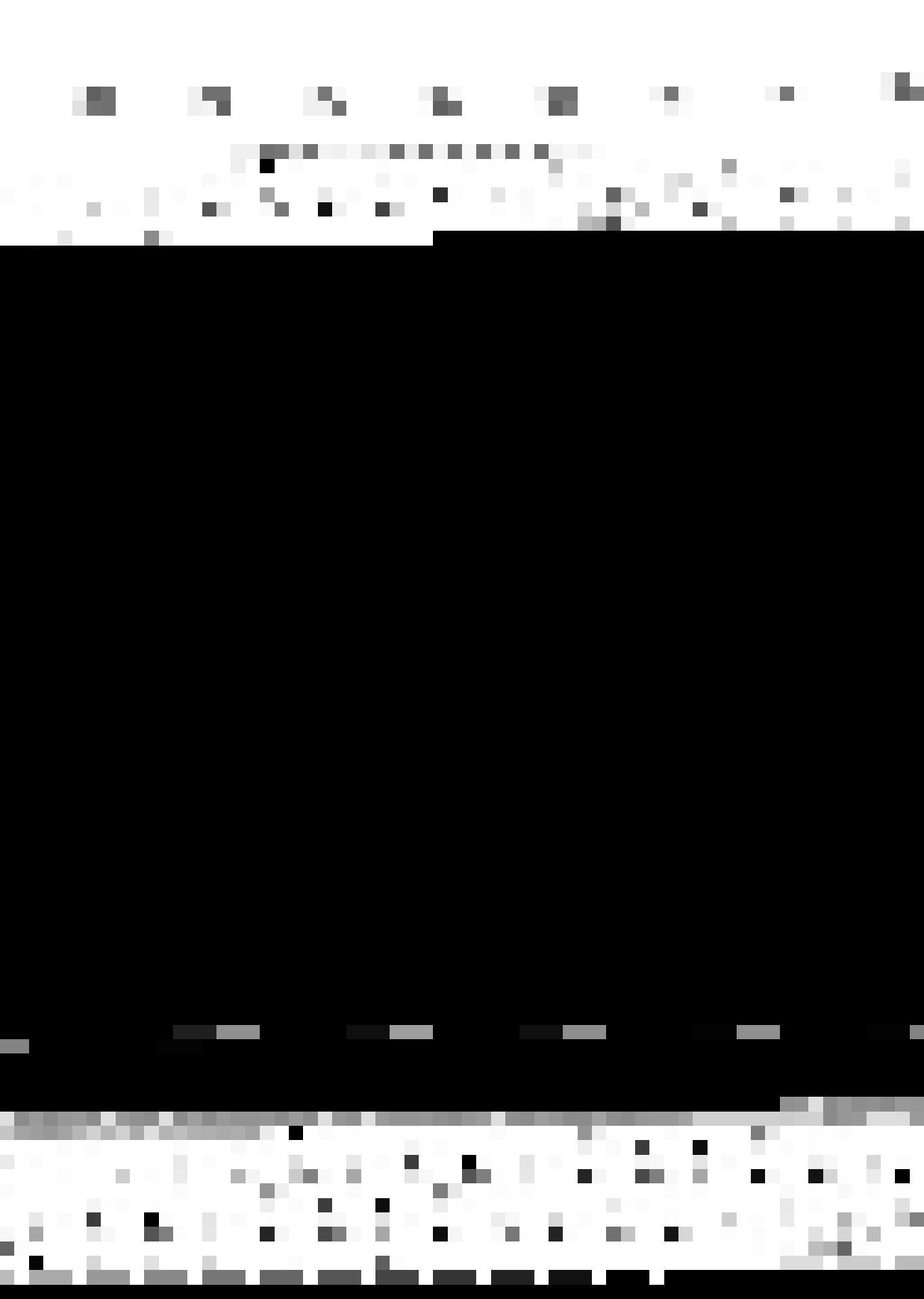


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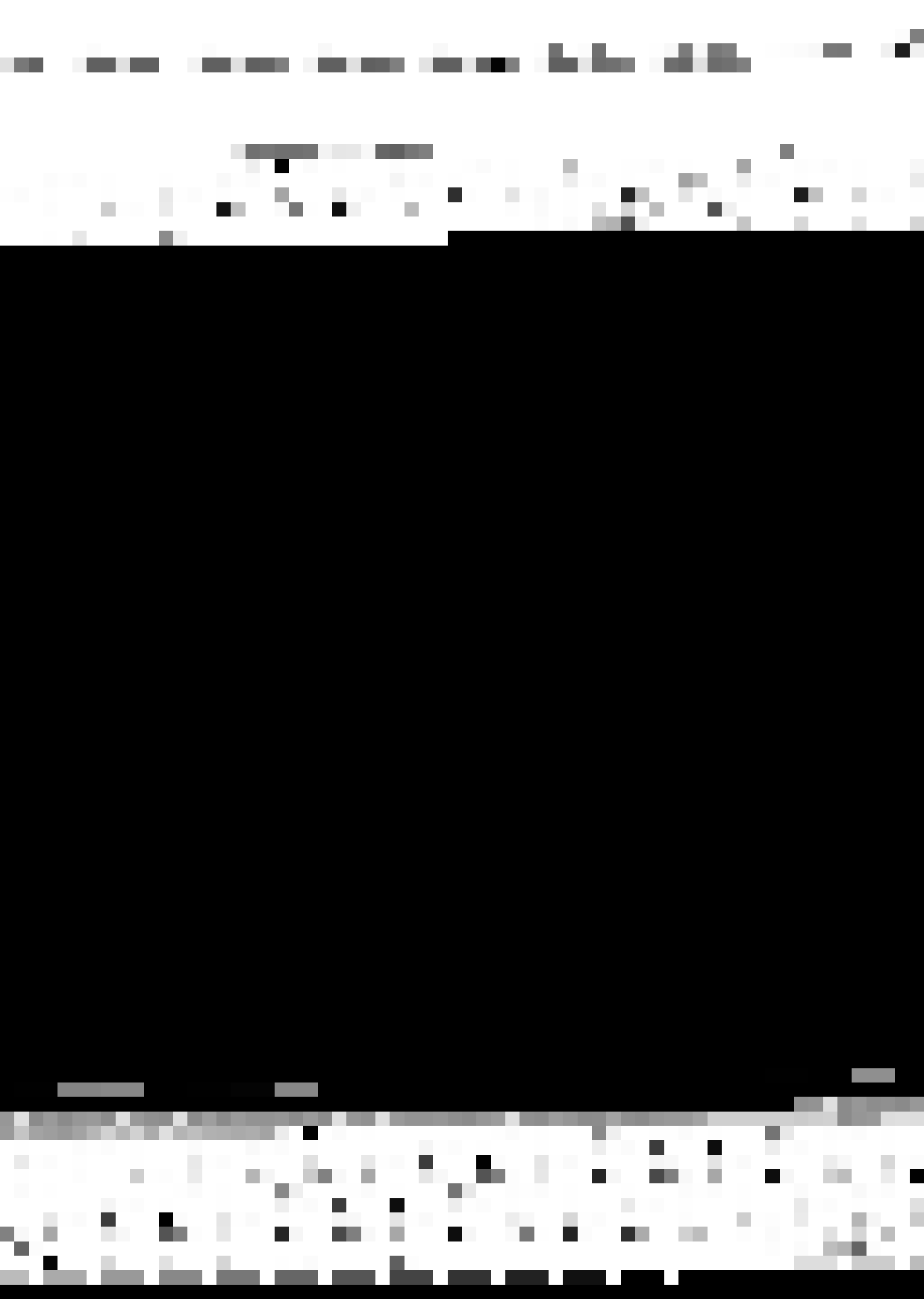




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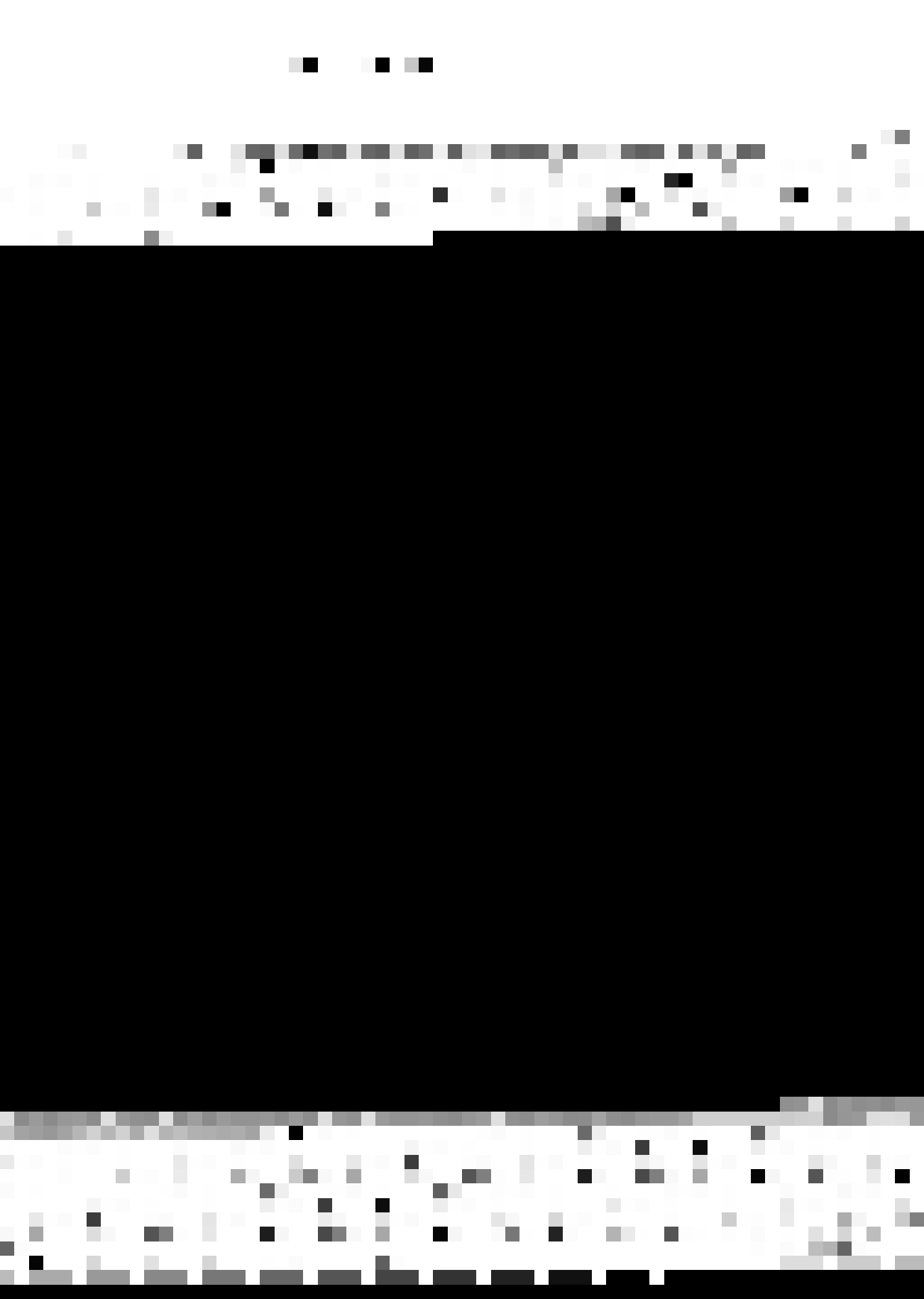
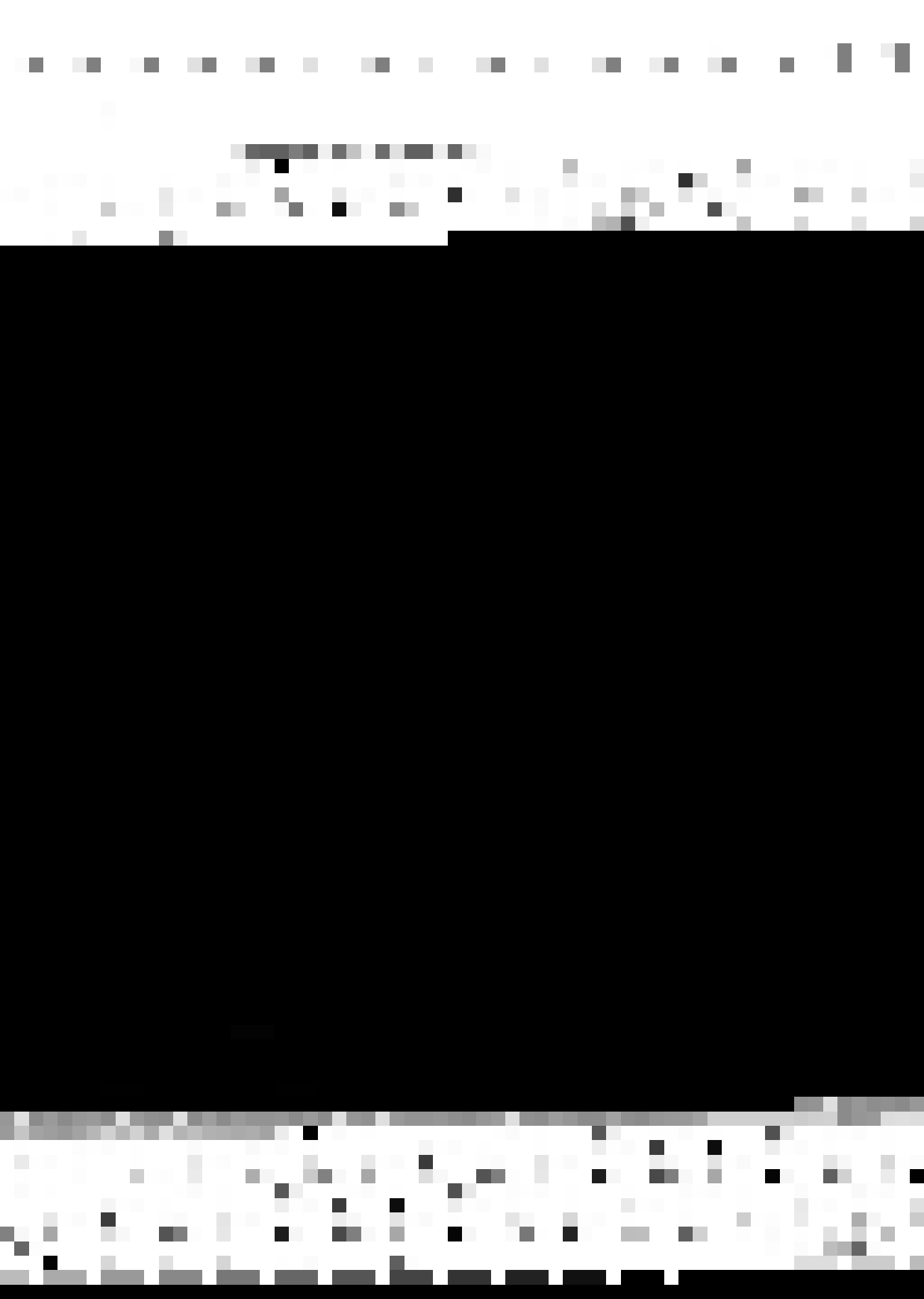


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# CHAPTER 1

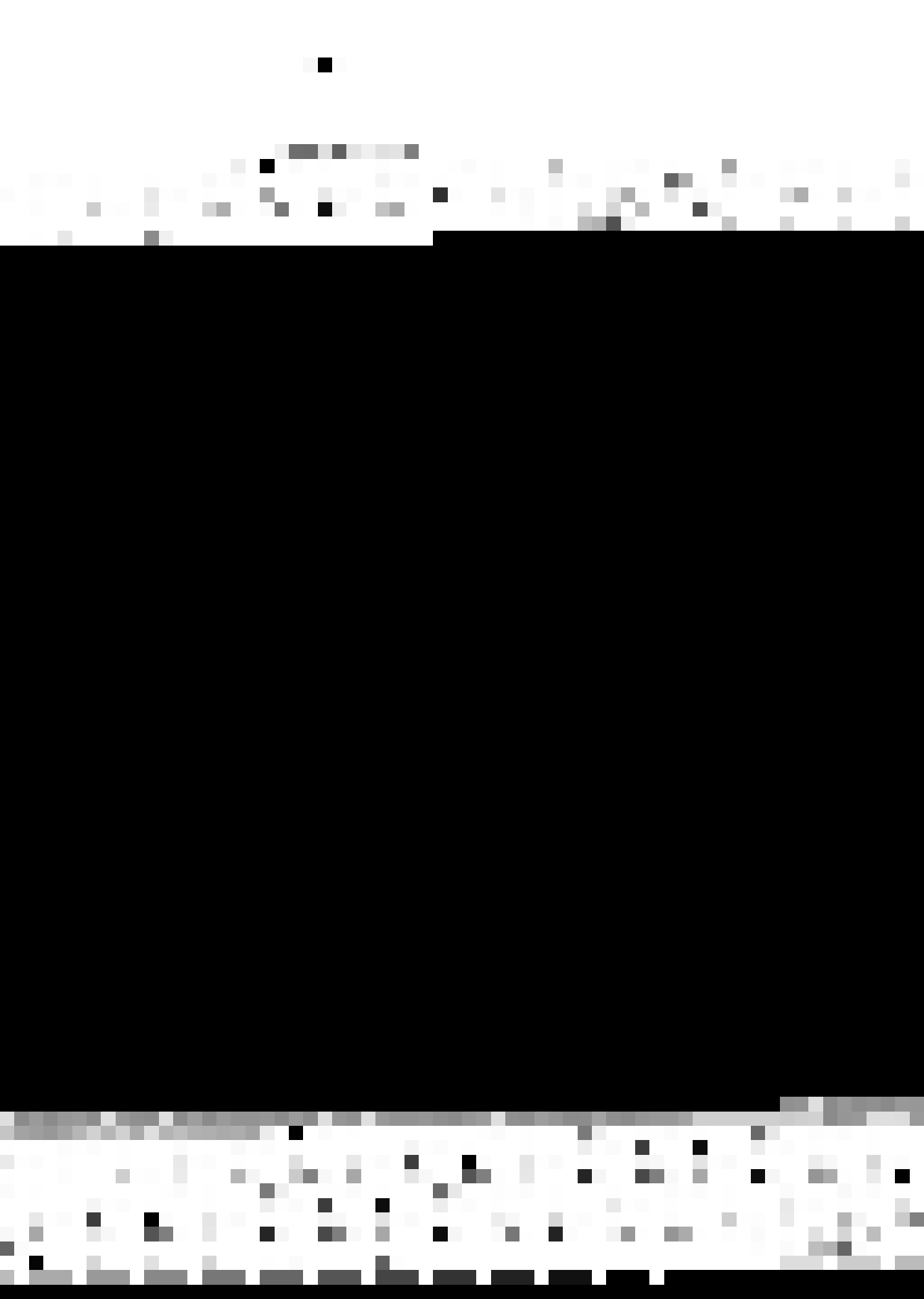
## INTRODUCTION

Powder metallurgy techniques appropriate to the various fabrication methods and tool applications are used for the manufacture of diamond impregnated tools, and for surface set diamond tools. Copper, various bronze compositions and ferrous metal powders are extensively used as a matrix for the manufacture of diamond tools. Copper and bronze alloys, unless combined with other harder metals are too soft for diamond tools. Iron, nickel and cobalt have appropriate but limited applications. All of the ferrous metals and especially iron are dangerously reactive with diamonds at elevated tool fabrication temperature.

Many of the early surface-set diamond tools used in the latter half of 19th century and the first half of this century were made by simply hand caulking the metal around the diamonds, so that diamond retention depended entirely on mechanical support. The matrix must hold the diamond particles in such a way that they are not pulled out, pushed in deeper, or moved around while the tool is cutting. The correct exposure of the diamond is vital for cutting efficiency. If the bond material is too hard, the diamonds will not be removed rapidly enough to keep the fresh edges exposed. Metal that is too soft will be easily eroded and will allow excessive exposure of the diamond which will lead to the loss of diamond. A further problem arises out of the fact that metals soft enough to optimize the rate of diamond exposure often fail to provide firm enough support to prevent the diamond from being progressively embedded into the metal.

Atomic bonding between the atoms of carbon in diamond and the





metal atoms can be achieved with appropriate metals and under appropriate thermal, chemical and physical conditions. Diamonds that are bonded in this way will obviously resist removal better than those that depend solely on mechanical support. The matrix used to retain and support the diamond particles must be selected with consideration for the type of tool, the properties of work piece material to be machined and the conditions under which the tool will be required to operate. Removal of metal around the diamonds should proceed at the maximum rate that can be allowed without the diamonds being dislodged from their positions. The key factors that determine choice of matrix metal include the characteristics of the abrasion or erosion to which tool will be exposed, the type and size of diamonds to be used and the tool fabrication process.

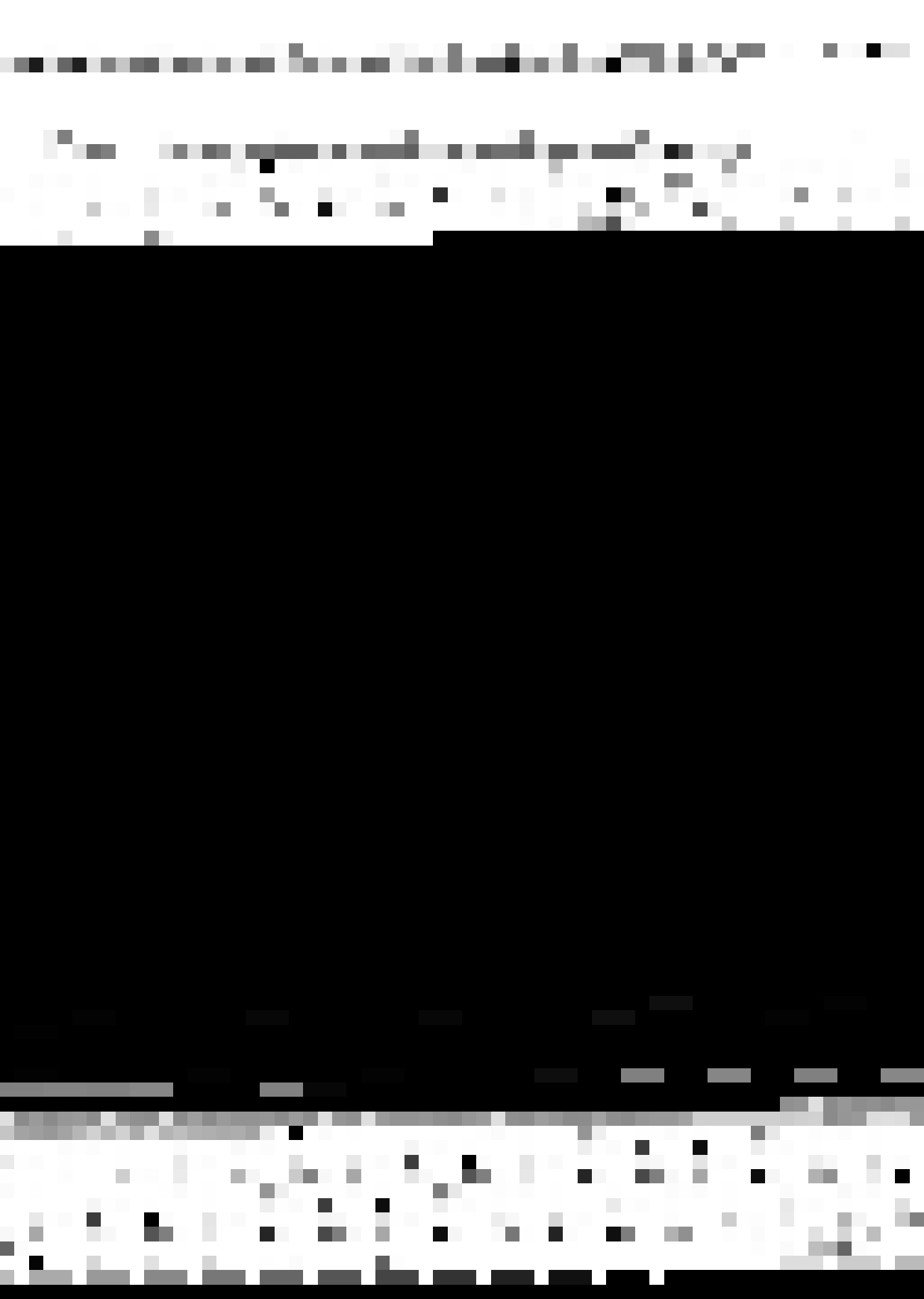
The effective use of diamond abrasives in metal bond tools depends to a large extent on the materials that are used to hold and support the diamond particles while they do their work. The metal matrix must support the diamonds firmly and must itself wear at just the optimum rate to keep the diamonds exposed. Techniques for maximizing this relationship include atomic bonding at the metal/diamond interface, proper mechanical support and degradation rate control. Many different compositions and many combinations of particle size and particle size distribution are necessary to accommodate the various tools, applications and tool fabrication methods. The work of diamond tool metallurgist is to assist diamond tool manufacturers in the selection of powder combination most suitable for each type of tool.

Recent techniques in the manufacture of diamond tools are by the rolling of metal-diamond powder. This technique provides the tool with a large working surface at a relatively small thickness. Only application of the process of rolling of powders enable us to achieve required uniform



density across the entire tool surface. The technique of manufacture of discs and belts from bronze binders has been worked out.

Chapter 2 deals with the general aspects of the diamond dispersed metal matrix composite materials. In Chapter 3, the experimental set-up and procedure are given and the results are discussed in Chapter 4. In Chapter 5, the conclusions based on the present investigations are given. Chapter 6 gives the suggestions for the future work.



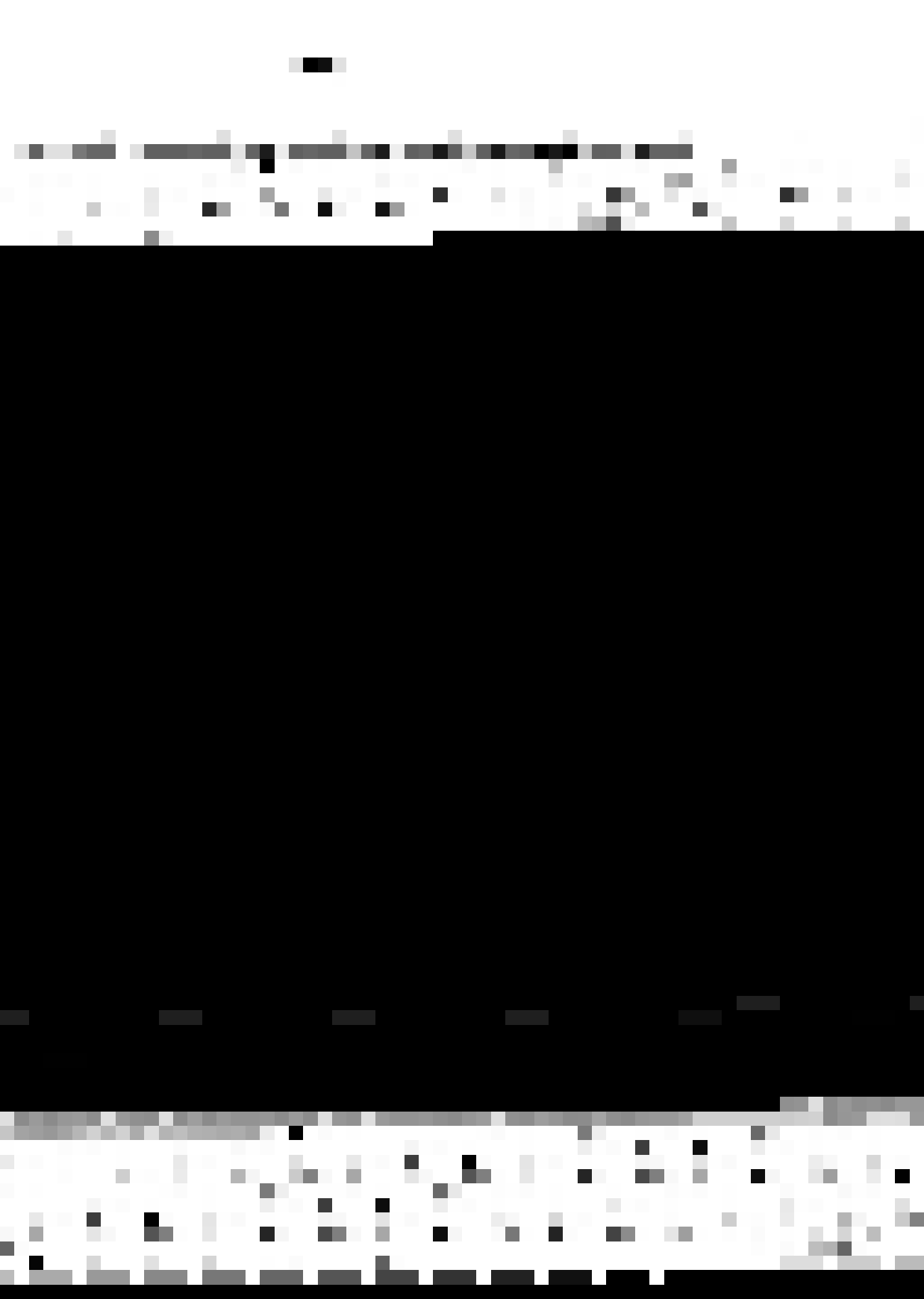
## CHAPTER 2

### DIAMOND DISPERSED METAL MATRIX COMPOSITE MATERIAL-GENERAL ASPECTS

#### 2.1 TECHNOLOGY USED IN THE DEVELOPMENT OF DIAMOND DISPERSED METAL MATRIX COMPOSITE TOOL MATERIAL

Since 1825 when the grinding wheel was first made in India (by dispersing corundum in shellac), there has been extensive effort to improve grinding and cutting wheel. Presently we have at our disposal four basic types of bonds to hold the abrasive grits: metal, resin, vitrified and electroplated. These bonds allow us to cover a wide range of applications.

The importance of metal bonds to hold diamond grits can not be over emphasized. The function of diamond grits is to remove material from the work. This purpose, however, can only be achieved if the diamond is tightly held in the bond. If the diamond breaks away from the metallic substrate (or bond) it is considered lost. The basic function of the bond on the surface set products is to provide a rigid base for large diamond grits on the case impregnated products, the wear resistance of the bond has to be compatible with the abrasiveness of the work so that the diamond grits are not prematurely torn away. In general most diamond powder or sintered diamond, which are used for technical applications, are produced by high pressure and high temperature conditions created by the skill of man. As sintered diamond is polycrystalline, it has very high strength and excellent wear resistance. As it is being used for cutting tool, drilling bits and drawing dies, the application usage of sintered diamond is very wide. Sintered diamond degrades under high temperature ( $>800-900^{\circ}\text{C}$ ). Though diamond is excellent material for cutting non-ferrous metal and



ceramics, diamond can not be used for cutting ferrous materials. Broadly there are two types of diamond. The first type is single crystal diamond which is very expensive and it is difficult to create in large size. The second type is sintered diamond which is produced by fine diamond particles bonded under high pressure. The diamond particles are bonded directly with interstices filled by ferrous or non-ferrous materials [1]. Table 2.1 shows the characteristics of the different matrix materials used for the production of diamond tools.

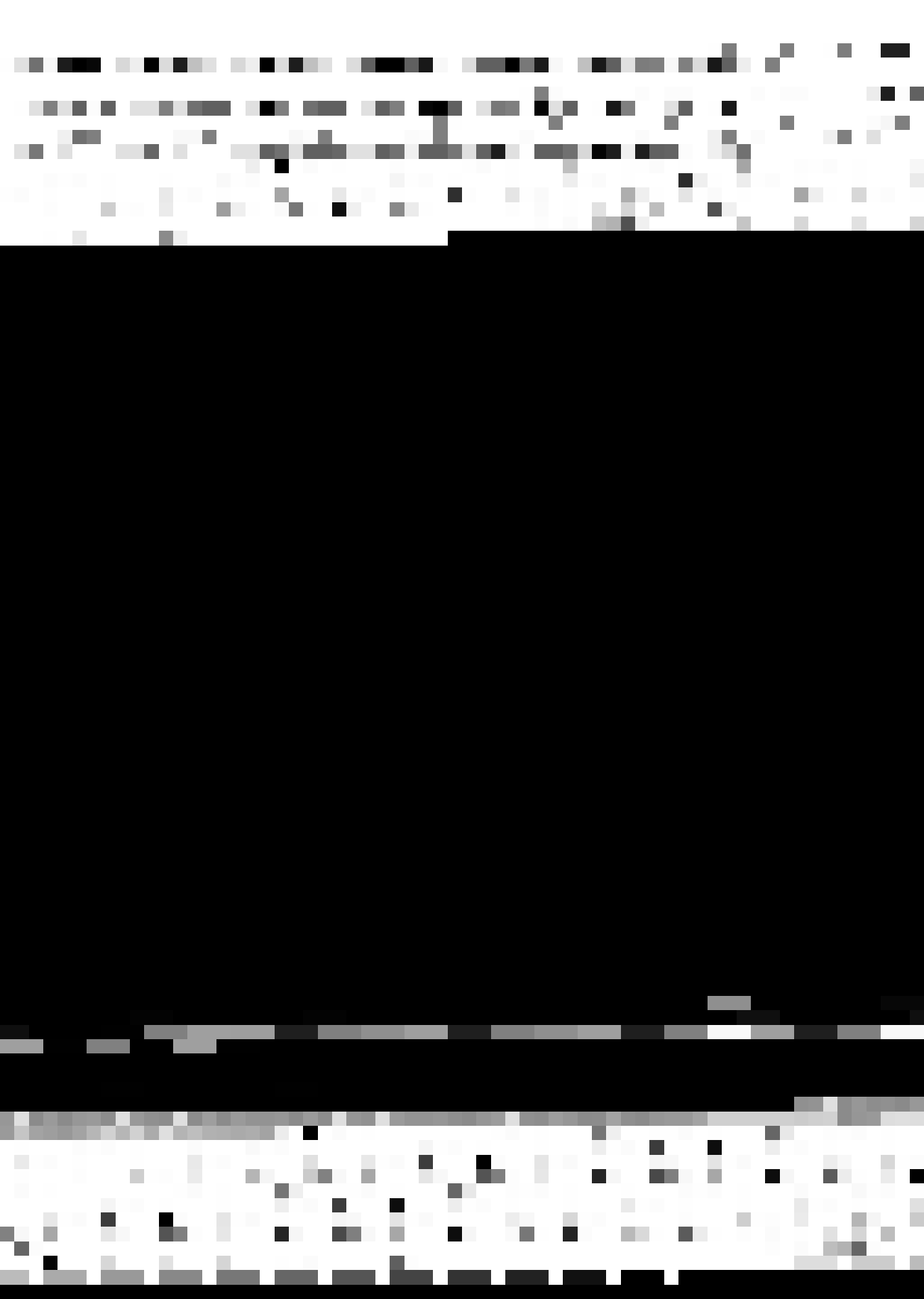
Table 2.1. Characteristics of the different matrix materials used for the production of diamond tools.

Type of bond	Bond strength	Cutting rate	Tool life
Metal bond	strong	low	long
Resin bond	weak	high	short
Vitrified bond	fairly strong	fairly high	fairly long
Electroplated bond	strong	fairly high	short

#### 2.1.1. Requirements Of A Good Metallurgical Bond

1) Wear resistance: The long, useful life of a diamond impregnated product is derived from the wear resistance of the metallurgical bond. The major efforts of the engineers and scientists in this field are directed toward developing metal bonds with controlled wear resistance. Abrasive work material like asphalt requires a very tough and durable bond (i.e., one with optimum balance of hardness and strength).





Without toughness and durability, the bond will wear faster than the diamond, resulting in the possibility of the diamond 'falling off' [2]. Fig. 2.1 depicts tightly held diamond grits protruding over the bond surface.

This will result in an inefficient use of the diamond, and the life of the product will be undesirably short. For relatively less abrasive material like cured concrete, the bond does not have to be as durable as for asphalt.

An extremely wear-resistant bond will wear very slowly compared to the diamond, causing the bond surface to polish. This phenomenon is commonly known as 'glaze over'. The protrusion of the diamond grits beyond the bond surface is negligible on a glazed over surface, as a result of the cutting action of the diamonds drops substantially. Fig.2.2 schematically represents the wear of bond matrix.

2. Mechanical strength: During operation, a diamond impregnated product often experiences abuse. If the matrix is not mechanically strong, it can shatter while being used, such incidents are occasionally encountered with a diamond product designed to cut or grind abrasive materials. The kind of highly wear resistant bond generally required for such application is inherently brittle.

3. Thermal expansion: Although it is very difficult to match the thermal expansion of the diamond with the thermal expansion of the metal bond, it is extremely desirable to minimize the difference. Inadequate cooling during the cutting operation can cause an excessive build up of heat in the bond matrix. If the bond expansion is much higher than the diamond expansion, there will be a tendency for the diamond grits to get loose and 'fall off'.

4. Thermal conductivity: The dissipation of heat from the cutting

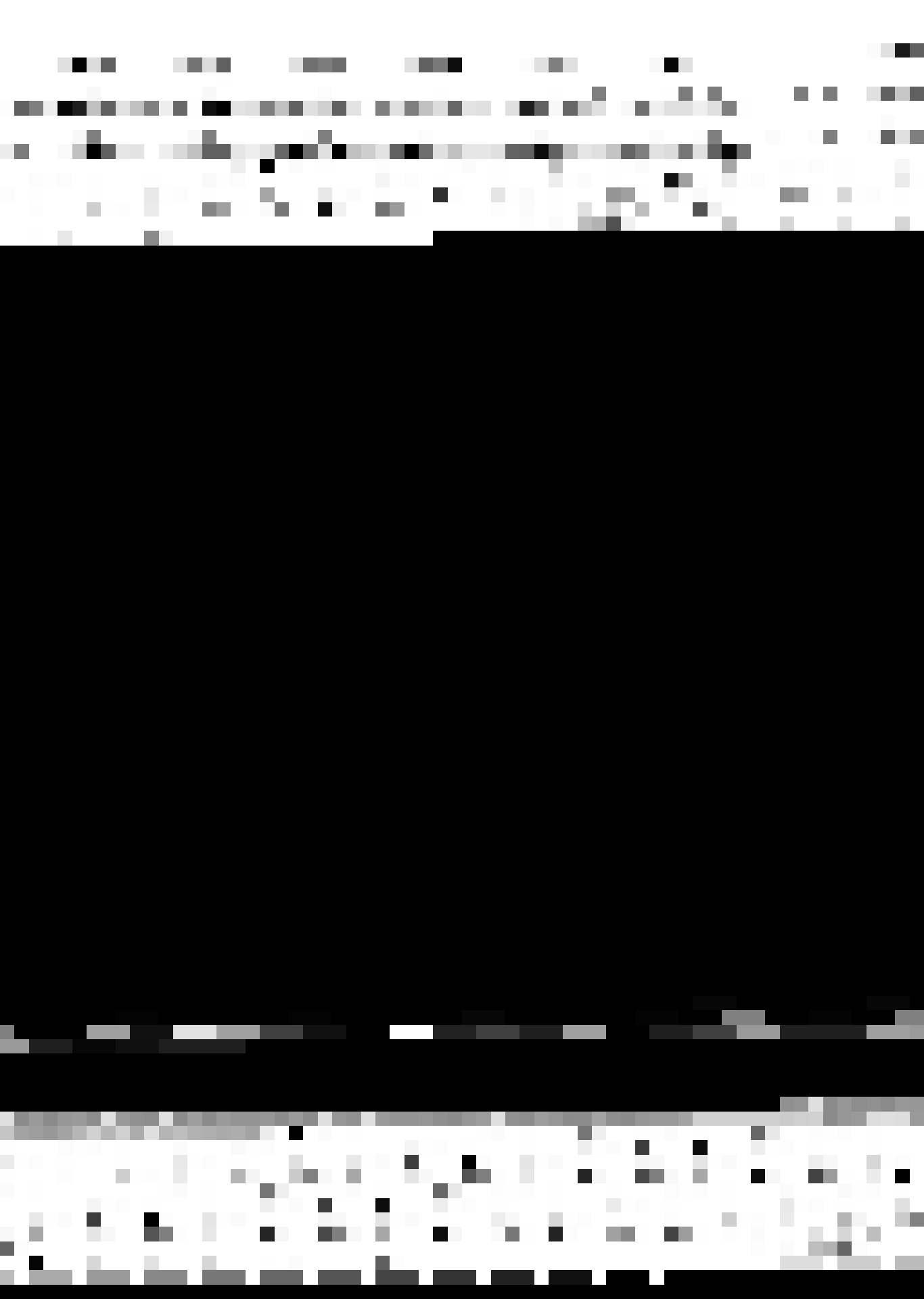
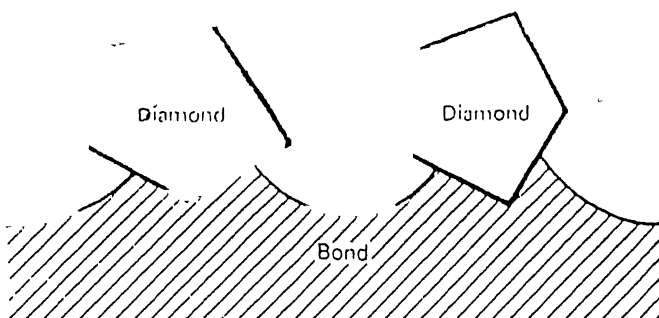
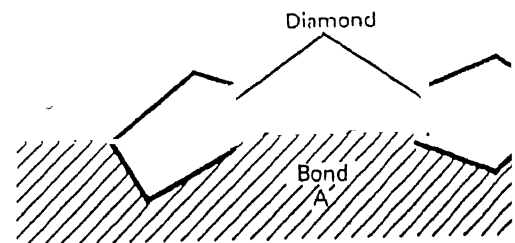




Fig 2.1 Tightly held diamond grits protruding above the bond surface



a Schematic view of excessive wear in the bond matrix.  
A lateral force can knock off diamond grits



b Schematic view of a normal diamond product surface  
with protrusion of diamond grits beyond the bond surface;  
Schematic view of a 'glazed over' surface with negligible  
protrusion of diamond grits beyond the bond surface

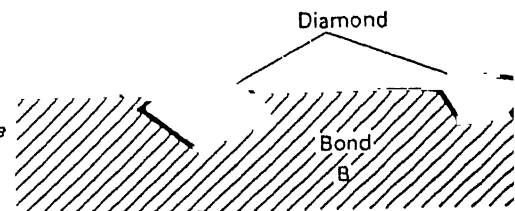
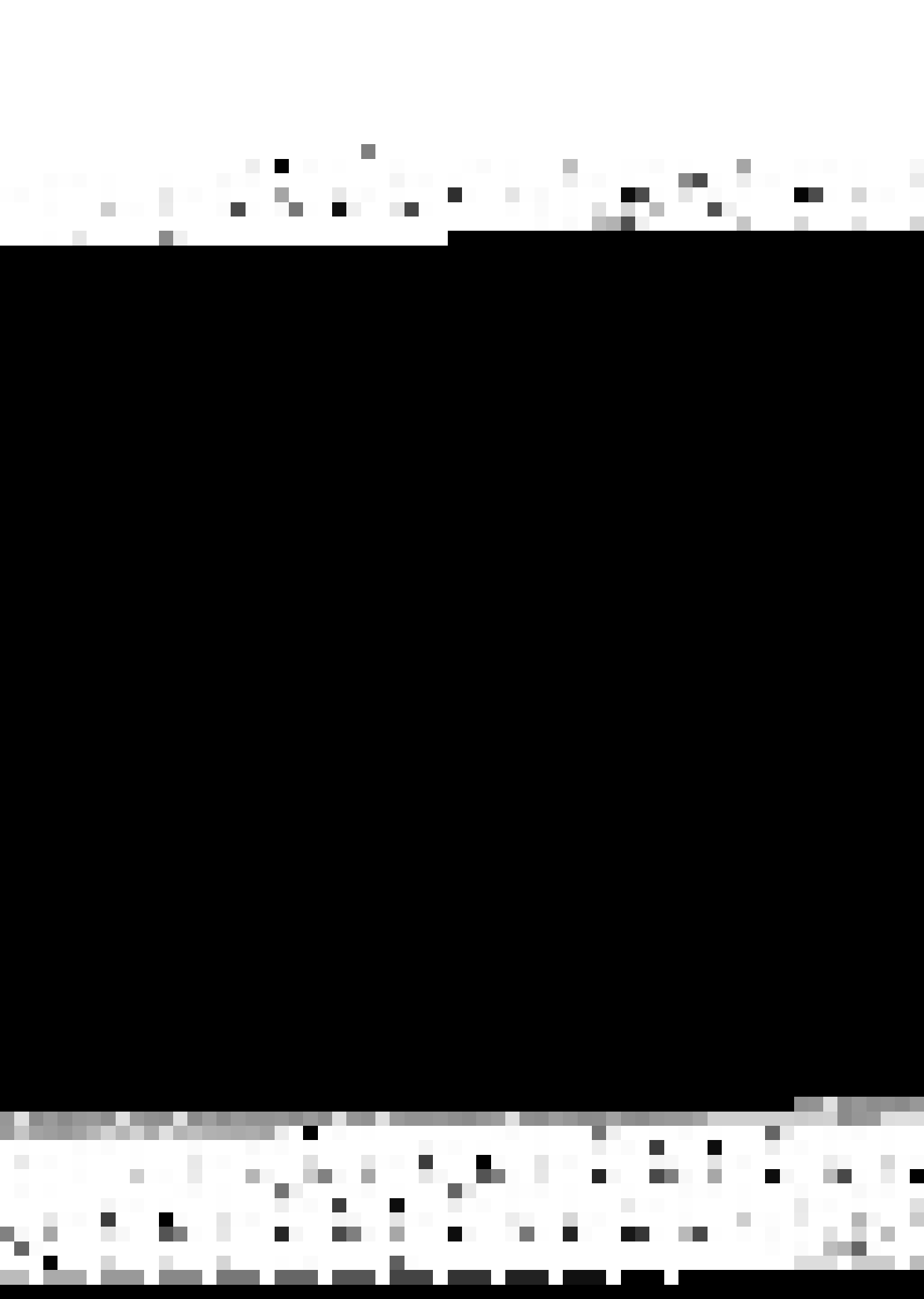


Fig 2.2 Schematic representation of the wear of bond matrix



area to other areas helps decrease the chances of damaging the diamond. A highly thermal conductive bond will help to achieve this purpose. Under dry cutting conditions, the thermal conductivity of the bond matrix becomes more important because air cooling is insufficient to dissipate heat from the cutting area [3].

5. "Wetting of diamond" with the bond matrix: In simple terms, the wetting of a solid with a liquid means that there is a mutual affinity between the participating solid and the liquid. Such affinity is the first step towards chemical bonding. During high temperature processing, the wetting of diamond grits by one or more ingredients of the matrix implies the existence of an affinity between the diamond and these ingredients. After cooling to room temperature, the 'wetting' can change into a bond equivalent of 'brazing'. If such 'brazing' occurs, the hold of the matrix on the diamond grits increase. This means a substantial reduction in premature diamond loss during the cutting operation and an increase in the useful life of the product. On the other hand, a lack of such 'brazing' implies a plain mechanical locking of the diamond grits in the bond matrix. As the matrix wears away the diamond grits are unlocked and begin to 'fall off'. Fig 2.3 depicts the mechanical locking of the diamond in the matrix. After erosion of the bond up to plane XX there is still perfect mechanical locking of diamond in the bond (contact area ABCDEFG). At the plane YY the diamond is not locked perfectly (contact area CDE).

6. Insolubility of diamond in the bond matrix: The total integrity of the diamond must be maintained in order to take advantage of the unique properties of diamond. During high temperature processing, some ingredients of a bond matrix have the tendency to aid in the graphitization process of diamond. If the presence of such ingredients is not minimized, a portion of the diamond content will be converted into graphite and the



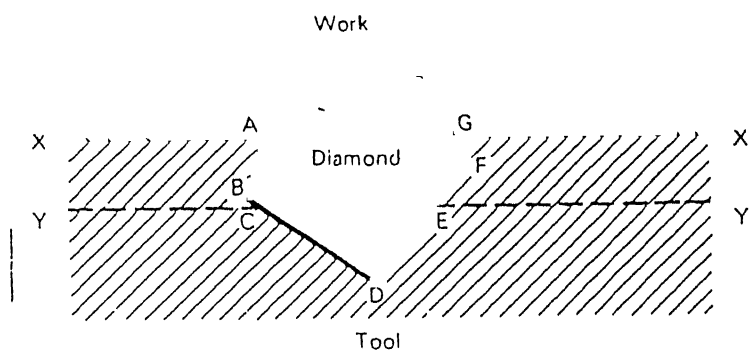
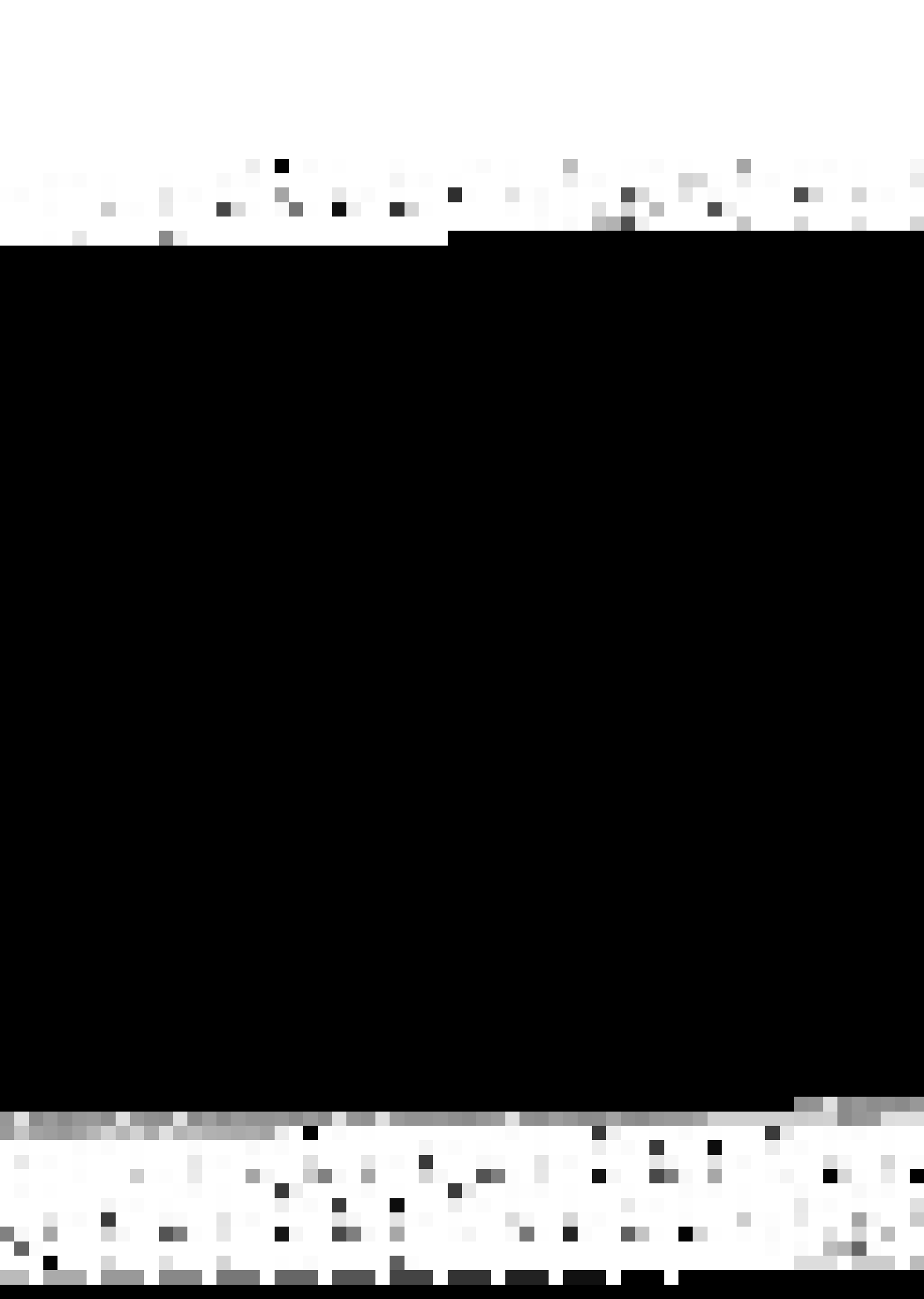


Fig 2.3 Mechanical locking of diamond in the matrix



Fig 2.4 Microstructure of a dense hot pressed matrix





life of the product will be shortened. The resulting graphite will generally dissolve in the matrix. In effect, graphitization of diamond results in the dissolution of diamond in the bond matrix [4].

### 2.1.2 Technical Parameters Involved In The Development Of A Bond Matrix

There are four basic parameters responsible for imparting the desirable properties discussed above to the bond matrix - composition, density, high temperature processing and hardness.

1. Composition: Compared to the other areas of powder metallurgy i.e., structural parts, contacts, magnetic materials, etc., there has not been adequate unified research efforts carried out in the field of diamond impregnated products to optimize the properties of bond matrices. As a result individual or companies have to conduct their own research work without the help of published literature. This has made the companies involved very secretive about the ingredients needed to achieve a certain matrix composition. To arrive at a certain matrix composition, consideration are given to the required properties case of fabrication and the economics of the process.

2. Density: Even if an optimum composition is found to provide the appropriate wear resistance and the other desirable properties in the bond, an absence of high density will make the product unsuitable for most diamond impregnated products. The lack of high density or the presence of high porosity cause two major drawbacks in a bond: low mechanical strength and low diamond retention capacity. High mechanical strength is necessary to avoid crumbling of the product during use. A high porosity (low density) will invariably decrease the surface area of the diamond grits in contact with the bond. As a result, a diamond grit can be detached from the matrix very easily. There are three commonly practiced methods of



removing the porosity (i.e., densification) from a bond composition: plain sintering, hot pressing and infiltration. In the plain sintering method, a cold compacted bond mixture (including diamond grits) is heated at a high temperature in a controlled atmosphere. The removal of porosity in this process is extremely slow. In the hot pressing method, heat and pressure are applied to a high temperature, the bond particles deform and move to achieve densification quickly. In the infiltration method, a low melting materials (inherently low wear resistance), a homogeneous wear resistant bond matrix is difficult to achieve this way. Fig 2.4 shows the microstructure of dense hot pressed matrix.

3. High temperature processing: In addition to densification, several other complicated metallurgical phenomena take place during high temperature processing, e.g., alloying, homogeneity, phase transformation and grain growth. For a given bond composition, these phenomena are controlled by the proper selection of time, temperature and pressure cycles. A deviation in these parameters will mean a deviation in the properties (i.e., wear resistance, mechanical strength, thermal expansion and thermal conductivity). In addition, the integrity of the diamond grits greatly depends on these processing parameters.

4. Hardness: Hardness is the most important control parameter. It is not an independent parameter responsible for providing the properties described earlier. A bond composition properly densified during high temperature operation (fixed time, temperature and pressure cycles) will achieve a narrow hardness range. If the composition deviates substantially, if densification is incomplete, or if the high temperature processing is faulty, hardness will not fall within the specified range [1].



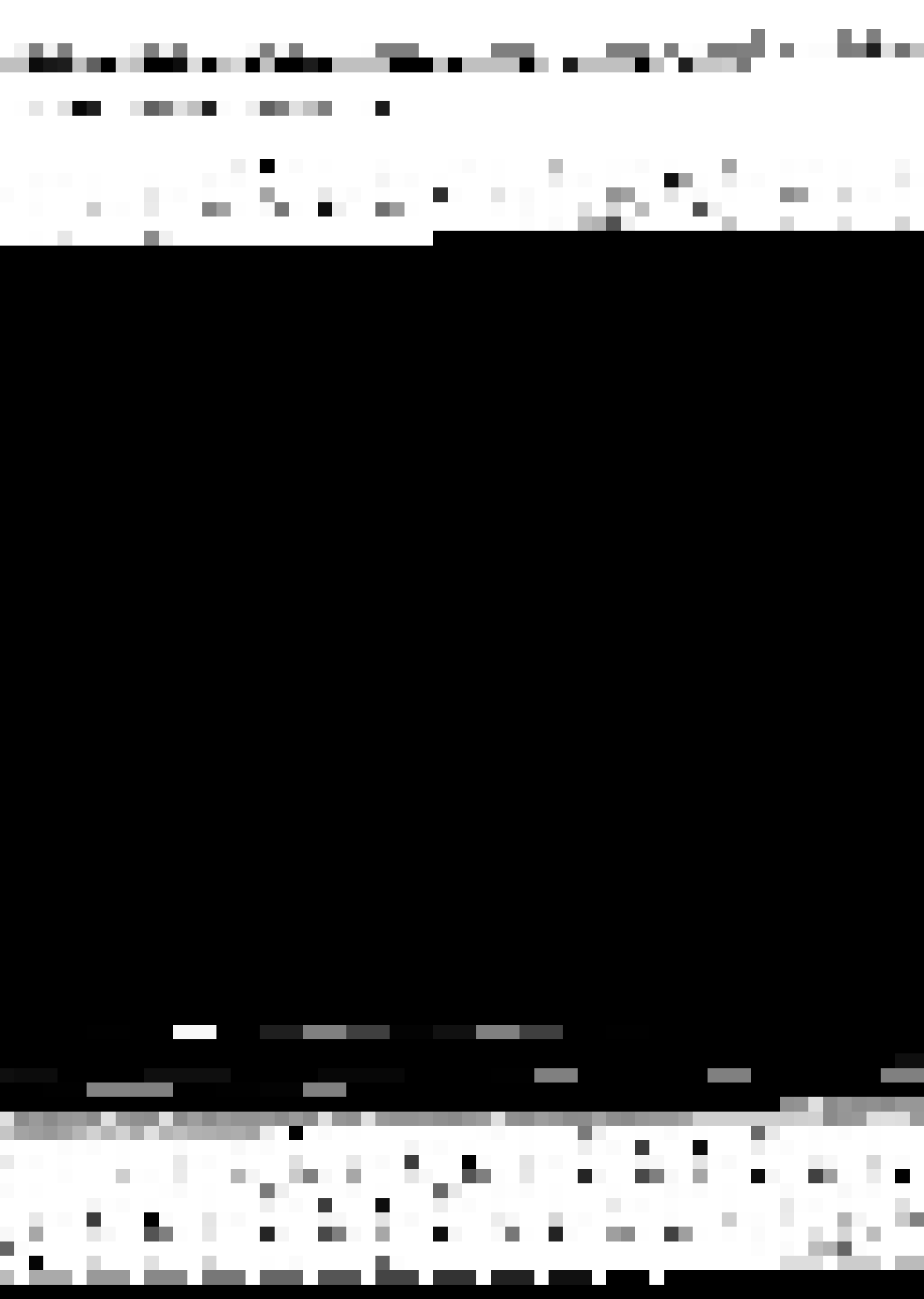
## 2.2 COMPARISON BETWEEN SINGLE CRYSTAL DIAMOND AND DIAMOND DISPERSED METAL MATRIX COMPOSITE COMPACT CUTTING TOOLS

Diamond cutting tools are now being made from diamond powder compacted and bonded to form materials comparable in strength to single crystal diamond. Here the physical properties of compact and single crystal tools and their performance as turning tools on a range of materials are compared. The compact material is designed as a replacement for single crystal diamond, but the two types of tool show the differences in behaviour which must be taken into account by the users [5].

Turning tools made of single crystal of diamond have two main fields of application. First, their high resistance to abrasion makes it possible to hold tight tolerances on abrasive material which would rapidly wear other types of tools. Secondly, it is possible to produce an exceptionally sharp edge on a diamond tool and thus produce extremely fine finishes of up to optical standards. Diamond tools are therefore widely used in industry but they have their own limitations, they tend to be somewhat variable in quality, that either in length of life or in the quality of the edge found on a given tool. They have a reputation of being easily damaged in handling. It is therefore of some interest that new materials are now available, the so called diamond compacts, which may be fabricated into metal cutting tools. There are different version in the market [6].

### 2.2.1 Single Crystal Diamond Tools

Progress towards producing more reliable tool has been rather slow. There are several reasons for this, but certainly the most important is the relatively large number of factors which cause a tool to fail. This



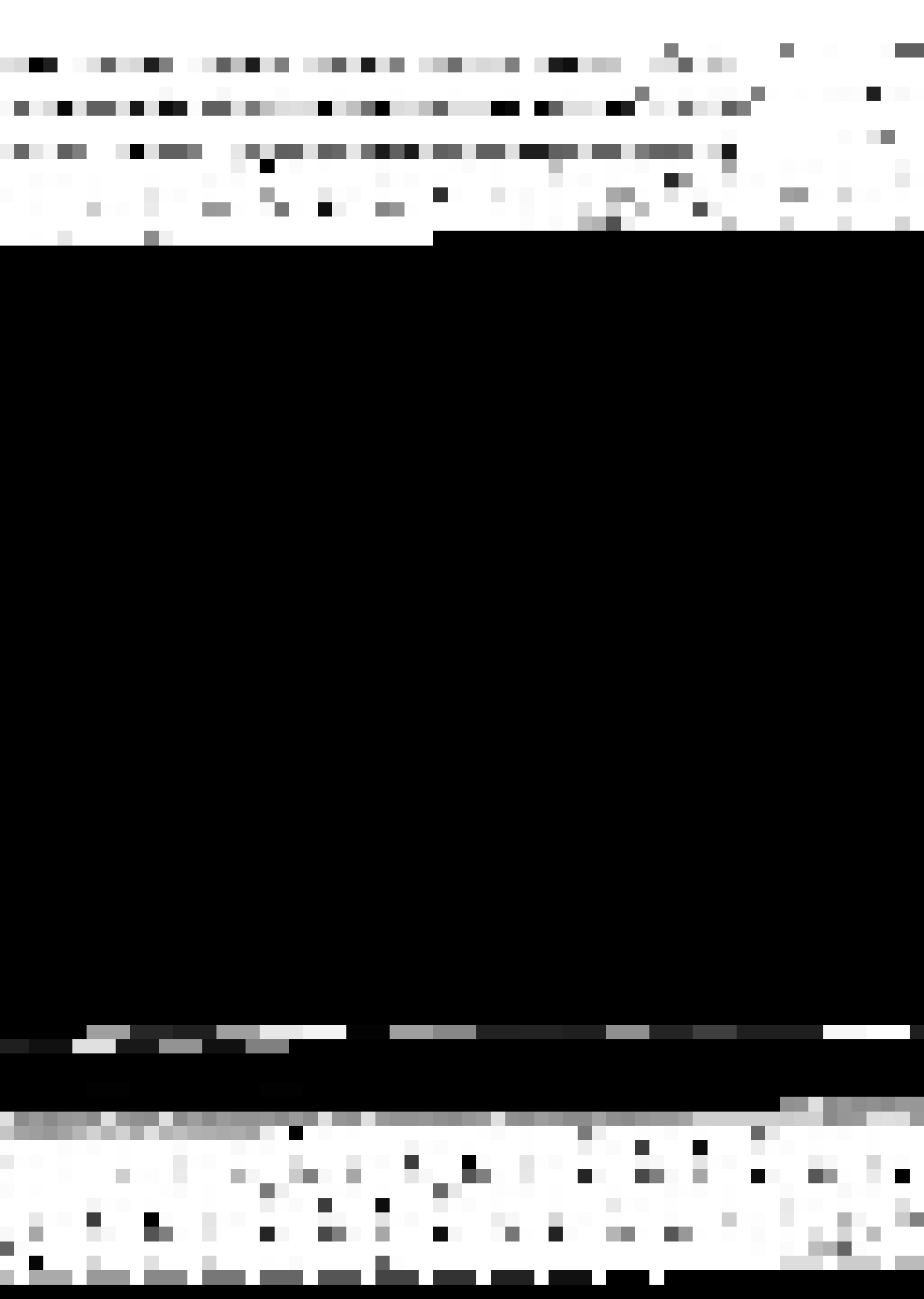
discourages both users and manufactures. A tool maker urged to select his diamonds more carefully will ask why he should choose better materials if it is only to be used on old and faulty lathes. The manufacturer will ask what is the point of installing better lathes if the diamond material itself is in question [7].

The resistance of diamonds to abrasion is remarkably dependent on the orientation of the diamond. It is also thought in the trade that some ways of orienting diamonds in tools are better than others, but very little quantitative information is available. The orientation of the diamond can have a very important influence on the life of a tool. Experiment was conducted with six geometrically similar round nosed turning tools made from selected good-quality diamonds. Even though All the tools were geometrically similar, three had one crystallographic orientation and three had another and their performance turning the Al-Si piston alloy LM13 is shown in Fig 2.5. The three tools in each group behaved similarly, but wear rates between the two groups differed by a factor of seven. Orientation may also have important indirect effects on the finish produced by the tool [8].

### 2.2.2. Machine Tools

The performance of a cutting tool is limited by the quality of machine tool in which it is mounted, and a diamond is less tolerant of inadequacies in the machine tool than most other cutting materials. Play or vibration is liable to cause chipping, so machine tools must be maintained in good condition and there is no point in seeking a better performance when the limitation is in the machine [5]. Mounting should be sufficiently rigid. It is also suggested that instead of designing the lather, from the diamond, a start should be made from the bed towards the





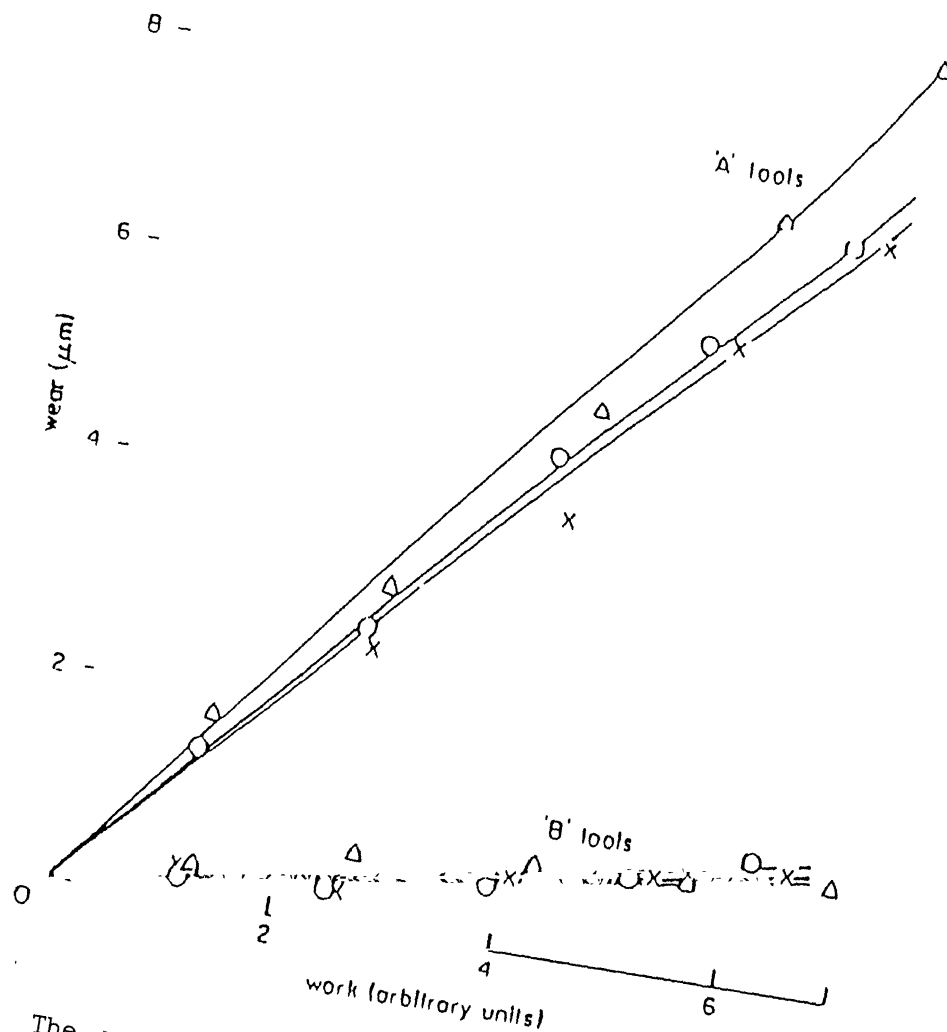
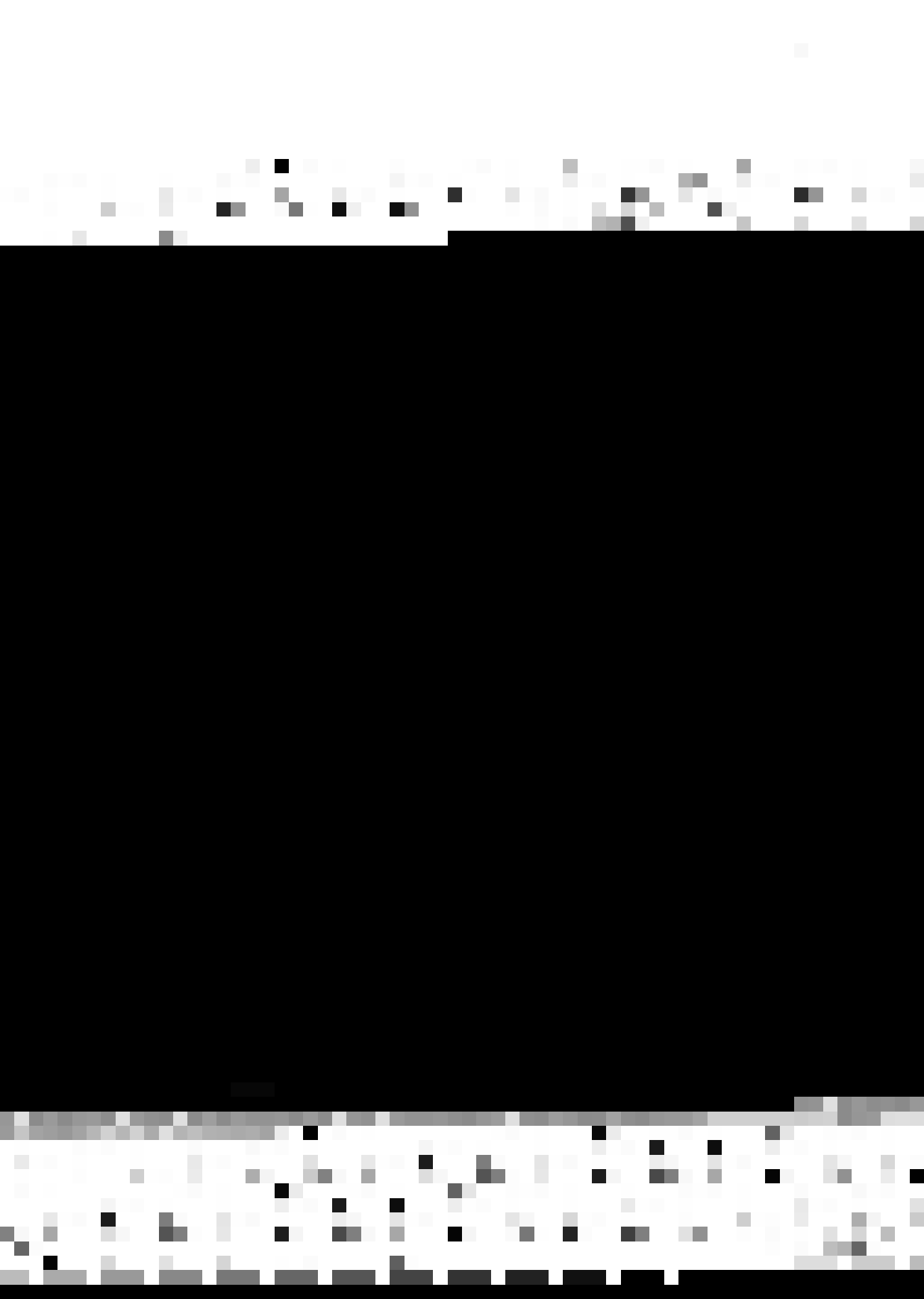


Fig 2.5 The wear of six similar round-nosed tools of two different crystallographic orientations A and B, when turning LM13



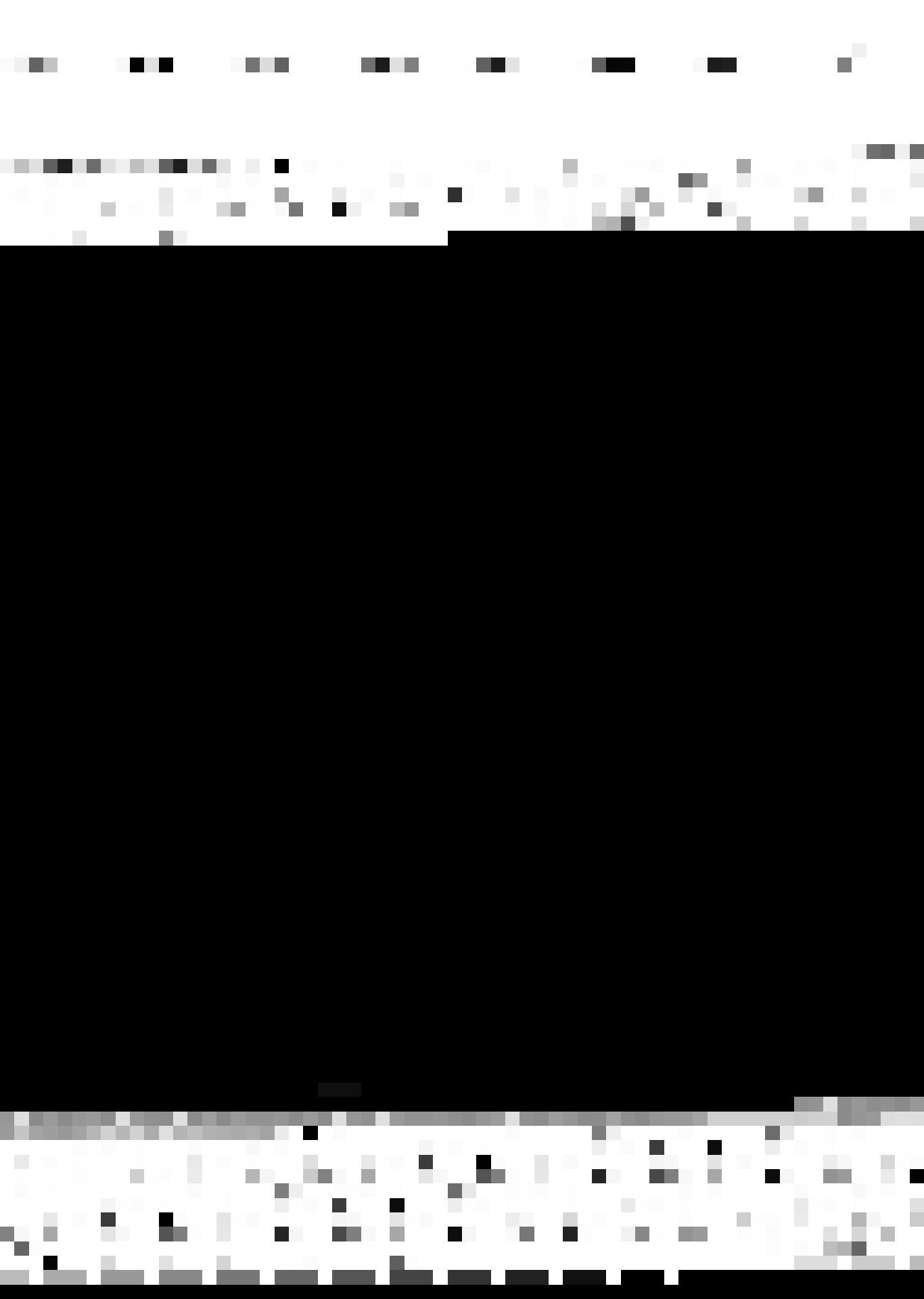
tool, so that the diamond had finally to be fitted into the available space as best it could.

### 2.2.3. Physical Characteristics Of Diamond Dispersed Metal Matrix Composite Compact

At first sight, diamond compact material offers the prospect of all the advantages of diamond, with none of its limitations. Thus, since it is polycrystalline, its physical properties are expected to be same in all directions. In particular it will not show the great differences in rates of abrasion characteristic of single crystal diamond. This suggests that the preparation and lapping of diamond tools from compact material may be an easier and less specialized task than shaping of natural diamonds. Because the compact is held together by a metallic bond which is softer and less brittle than the diamond, there is the prospect of obtaining a tougher material more resistant to fracture and chipping. As the compact is a man made product it should be possible to produce a material of more constant quality than is possible material is manufactured from diamond powder which can be readily synthesized, the potential supply is virtually inexhaustible. It is important to describe some important physical characteristics of diamond compact tool which differ from single crystal and the influence of these properties on the performance of compacts used as cutting tools [9].

#### (i) Polycrystalline Structure:

The most characteristic feature of a compact is that it is made of small diamond particles of the order of few microns in diameter, compacted together by some form of metal bond. The particles of diamond will be oriented in all the directions, some particles presenting a very hard aspect in a given direction, others a much softer aspect in the same



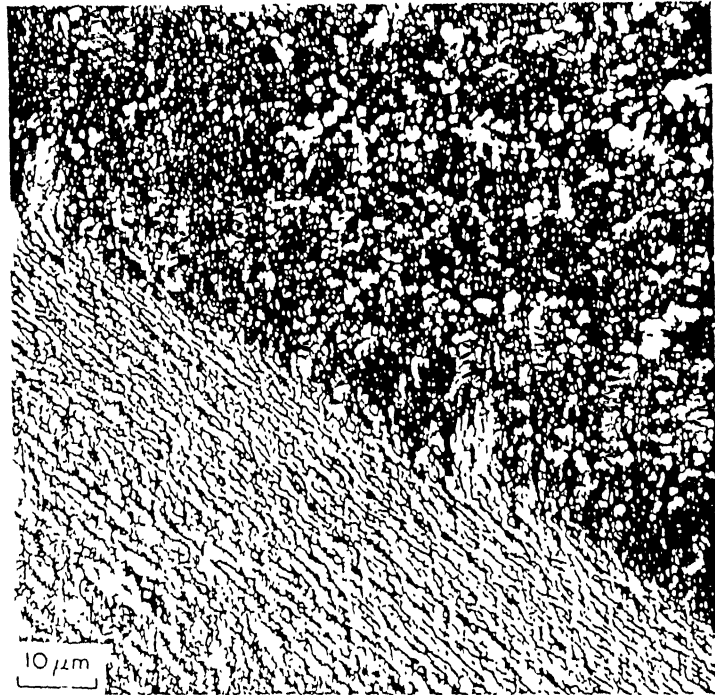
direction. It follows that it will be very difficult, if not impossible, to polish an edge more sharp than a fraction of the grain size. Similarly, it will hardly be possible to polish the table and flanks of a tool to as good finish as can be obtained on a correctly oriented natural stone. SEM of edge of a compact tool and single crystal diamond tool showing table and flank are shown in Fig 2.6.

(ii) Abrasion Resistance And Toughness:

The abrasion resistance of a compact may be evaluated by making abrasion with a bonded wheel, as in the case of single crystal diamonds. It is seen that most resistant compact has an abrasion resistance intermediate between the highest and lowest values observed on single crystal diamond on the other hand, one of the other diamond compacts was much more easily abraded.

The toughness of compact material may be assessed by observing its resistance to the formation of ring cracks. The high resistance of some compact material to abrasion; this is a very desirable property in the finished tool, but poses some difficulty in its fabrication. Natural diamonds are shaped to form a tool by, wherever possible, polishing in their softest directions. Even so this tends to be a slow process. It is therefore an unwelcome feature of most compacts that the diamond grains will present themselves in harder directions to the polisher, so the shaping of compact tools is not altogether easy. It is true that they offer the advantage of being isotropic, so the polisher does not need to know all the tricks of directional properties of the diamond. On the other hand, he still has to deal with a remarkable abrasion-resistant material. Increased toughness of the compact which comes from the metal bond. The compact is tougher essentially because the metal bond is softer and yields more readily. Hand in hand with this yielding of the metal goes readiness



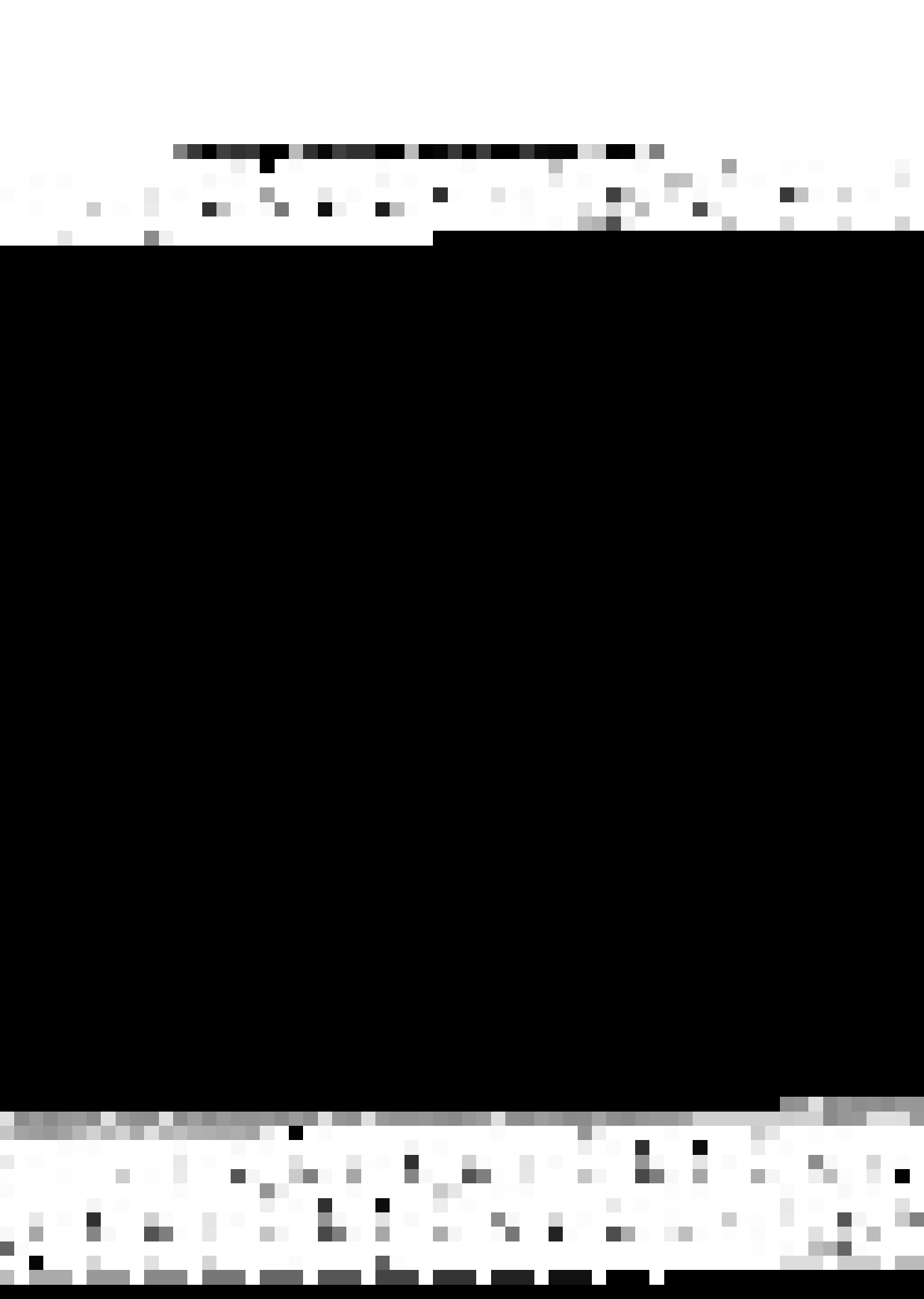


a. The edge of a compact tool showing table and flank (scanning electron micrograph)



b. The edge of a single-crystal diamond tool showing table and flank (scanning electron micrograph)





to soften at a lower temperature than the diamond. Hence a compact will be more susceptible to deterioration through heating than the corresponding single crystal tool. The greater expansion of metal bond may also be another factor tending to deterioration at high temperature [5].

(iii) Thermal Conductivity:

Single crystal diamonds are very good conductors of heat at room temperature. This plays an important part in removing the heat from the tip of the cutting tool and thus maintaining it's quality. In compact material the small grains of diamond will have the same conductivity as the bulk material, but the heat flow will be impeded by the innumerable boundaries between the grains and the metal matrix. Also, the conductivity of the matrix itself will in all probability be lower than that of diamond. No figures for the thermal conductivity of compact are at present available but from various literature sources, it is expected that it will be lower than single crystal by a factor of at least 2 or 3, and the tip of the tool to run correspondingly hotter.

(iv) Chemical Constitution:

The wear of a tool sometimes occur by chemical rather than a physical processes. The wear of natural diamond on steel suggest that wear of diamond takes place either by a diffusion process in the steel or by a transition of the diamond to graphite [7]. Likewise, there is an evidence that the wear rates of diamond grinding wheels are a function of the chemical constitution of steel. In such cases the behaviour of the compact material to be significantly different. The metallic bond material will play an intimate part in the wear processes.



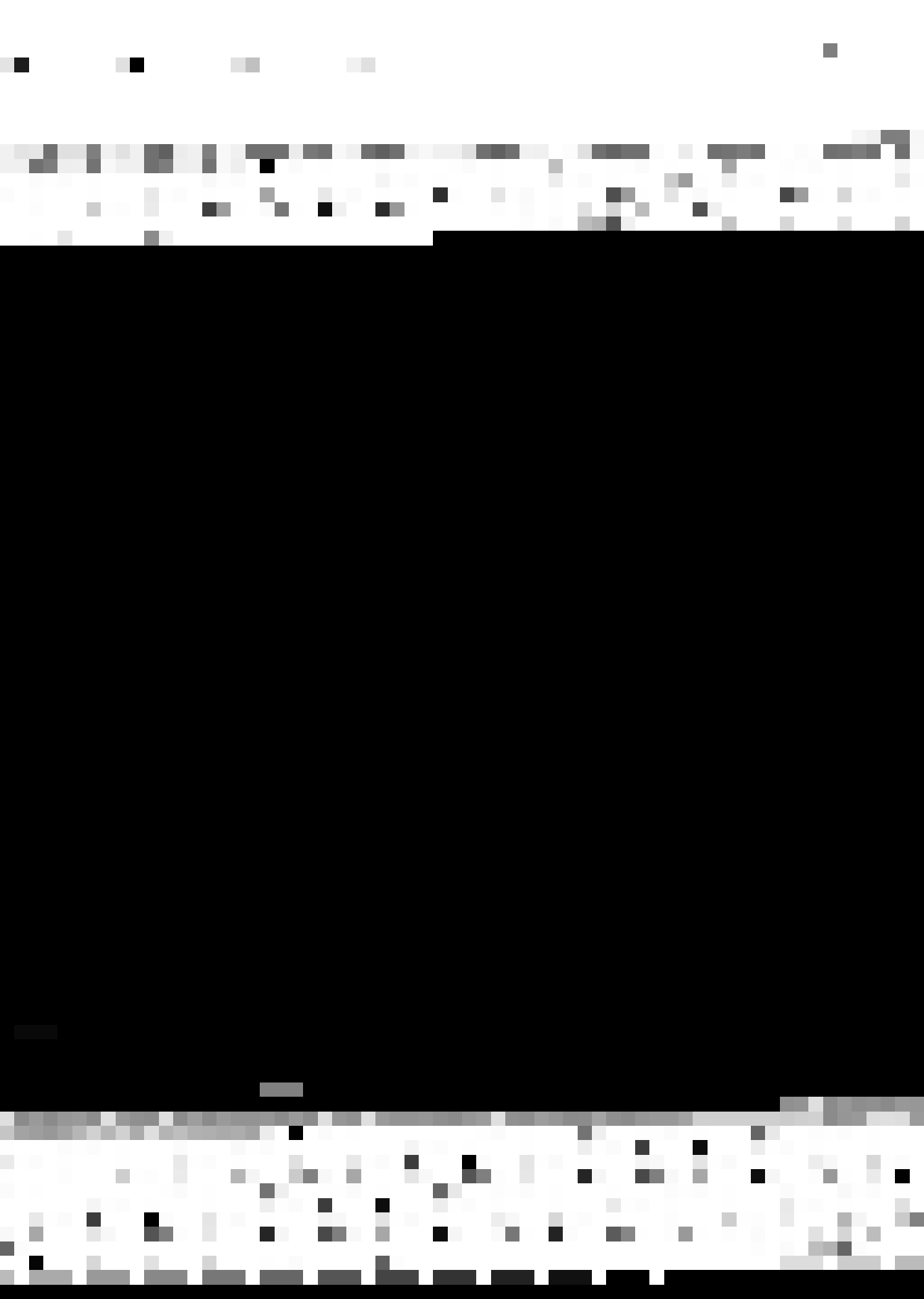
#### (v) Variability Of Natural Diamonds And Compacts:

Compact material is man made and can, in principle, be subjected to a close quality control to give a uniform performance. However, it is by no means easy to maintain the rather severe conditions of pressure and temperature necessary for a completely uniform synthesis. More experience is required in the fabrication of compacts. Various differences between compact and natural diamond tools have been described. The most striking characteristics of the two tools are the toughness of the compact and very fine edge which can be achieved on the natural stone. There are also several other differences which may be very important in particular applications. Thus each material has its own field and the user should appreciate this to obtain the best results [5,6].

### 2.3 AFFINITY OF DIAMONDS FOR METALS

The utility of diamond tools widely ranges from grinding wheels to die and saw with increasing supply of synthetic diamond. Especially, diamond abrasive grains as an excellent material with an unpenetrative hardness are widely used for grinding sintered carbides and ceramics which are extremely difficult to machine with conventional abrasive grains. Furthermore, grinding steels are also ground successively with diamond abrasive grains coated with metal. For the effective use of diamond tools, however, one of the practical subjects to be solved is the improvement of bonding matrices. Much efforts are concentrated on the development of bonding matrices which adhere to diamond chemically, because the grits in the diamond tools are mechanically held by impregnation in a manufacturing process [10].

Studies of the nature of the interface bonds between diamond and



metals are of great theoretical interest. In practice, strong diamond-to-metal bonding is important for the production of tools(both abrasive and cutting tools) are to a great extent, determined by the tenacity with which a grit particle, tool stone or tool blank is held in the metal matrix or tool holder. With purely mechanical particle retention, the diamond grits in an abrasive will become exposed as the surrounding metal wears away, and sooner or later pull out will occur. Secure retention of diamond particles can only be ensured by forming a chemical bond between the diamond and the matrix constituents, which may be attained when metals showing a high chemical affinity to carbon (carbide forming elements, or elements dissolving carbon in substantial quantities), are employed.

While a strong affinity of diamond has been discussed for transition metals and attributed to the formation of carbides [11], diamond abrasive grains coated with titanium were reported to have excellent wear resistance achieved by the chemical bonding between matrices and grains. Increased grinding ratio due to the improvement in adhesion between diamond and the bond has been shown by using Cu-Sn-Ti alloys for bonding matrix (wetting and bonding of diamond by Cu-Ti alloys). The thermal stability of diamond is not always sufficient. It has been reported that diamond was thermally eroded in contact with the environmental elements of Fe, Ni and Ti. These metals are used as catalyzer in the synthesis of diamond. Therefore, the affinity of diamond for metals should be thoroughly examined with thermal erosion [12].

It will be possibly assumed that the adhesional wetting mechanism is applicable to the contact between diamond and metals in a manufacturing process of diamond tools. Wettability is quantitatively evaluated by following eqn., i.e., from the contact angle formed by liquid metal on the



surface of diamond in the wetting test by the sessile drop method,

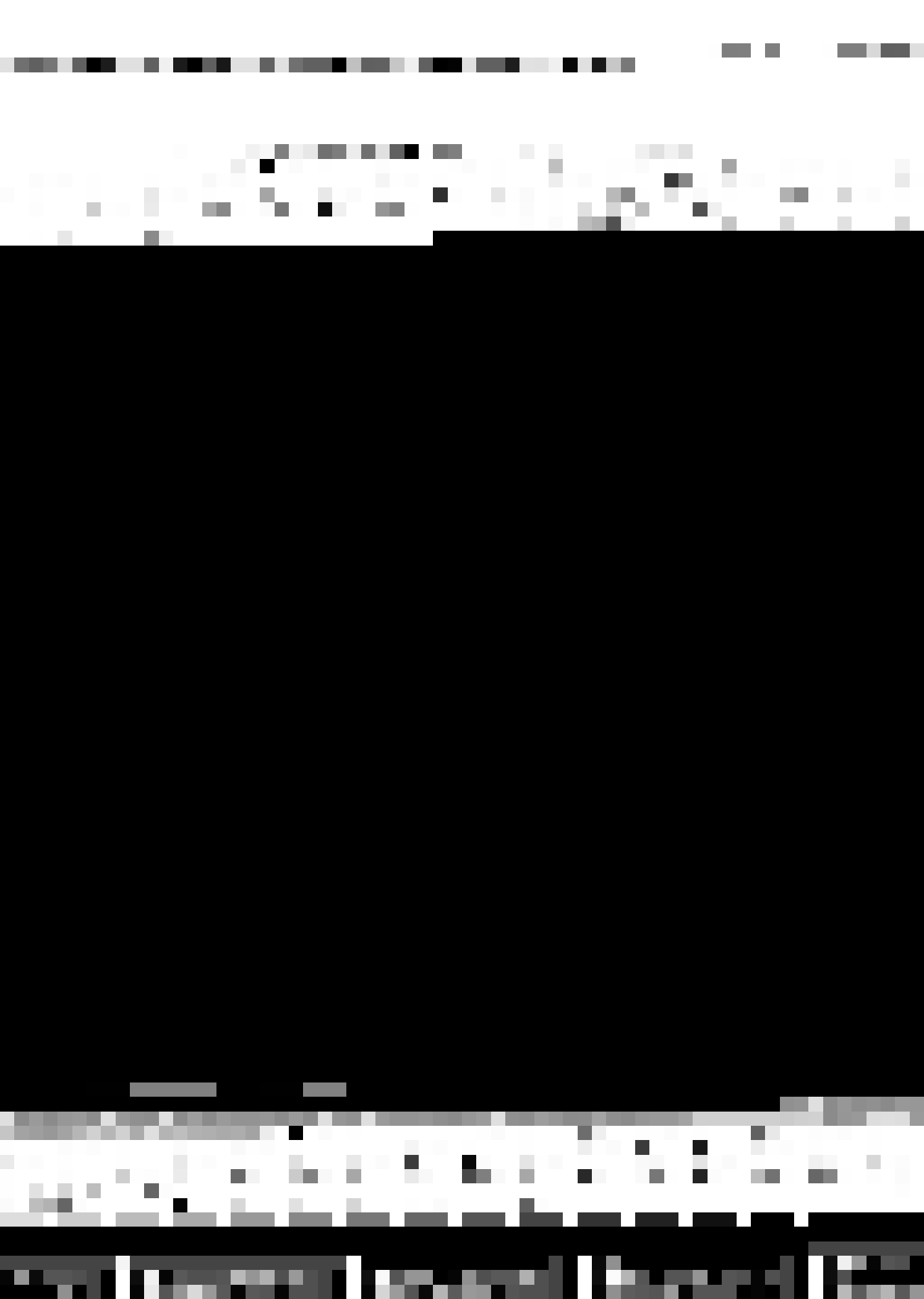
$$\frac{W_a}{W_c} = \frac{1}{2} (1 + \cos\theta) \quad (2.1)$$

where,  $\frac{W_a}{W_c}$  is the ratio of adhesion vs cohesion of liquid metal in its total molecular energy and  $\theta$  is the contact angle. The above equation is enough applicable to the wetting on a surface of diamond which is isotropic in the lattice distance and the surface strain [11].

It has been stated that metals showing low chemical affinity to carbon (metal of side B-subgroups of the periodic table), ie., those not forming stable carbides and not dissolving carbon to any significant extent, do not wet the diamond surface ( $\theta > 90^\circ$ ). The bonding strength of such metals in the solid state to diamond is very low. The incorporation in a metal alloy of even minute quantities of elements that are chemically active with respect to carbon (carbide forming metals result in a sharp decrease in the contact angle ( $\theta \ll 90^\circ$ ), an increase by an order of magnitude ) in the adhesion work, and also a substantial enhancement of the strength with diamond to metal bonding.

Nevertheless, such weakening factors as strains in the near contact zone, low mechanical strength of intermediate layers, possible allotropic transformations of one or both phases comprising the pair in contact, as well as other detrimental factors, may result in a low actual strength of the bond. Therefore, between the adhesion work of a molten alloy and the solid surface on one hand, and the mechanical strength of bond between a solidified alloy and the same solid surface on the other hand only a general correlation is observed. Studies of the mechanical strength of diamond-to-metal bonds and comparison of the data with the data of the adhesion work are thus important. Very few investigations are





reported in the literature. The main factors decreasing the strength of a diamond-to-metal bond are (a) diffusion porosity and (b) diamond surface graphitization. By eliminating the action of the above factors, it is possible to retain the high strength of a diamond-to-metal bond which may be obtained when metals showing high chemical affinity to carbon are employed [13].

The following conclusions are obtained on the cutting of soft metals to diamond, of Sn to metal evaporated diamond and on thermal erosion of diamond heated in powders of pure metals at  $900^{\circ}\text{C}$  [13].

1. Lower affinity of diamond is observed for all of combinations with soft metals.

2. Each plane of diamond shows the different wettabilities depending on its crystallographic orientation. The  $\{100\}$  plane shows better wetting comparing with the  $\{110\}$  and  $\{111\}$  planes.

3. Physical adhesion due to Van der Waals force is verified to be predominant in the wetting of soft metals to diamond.

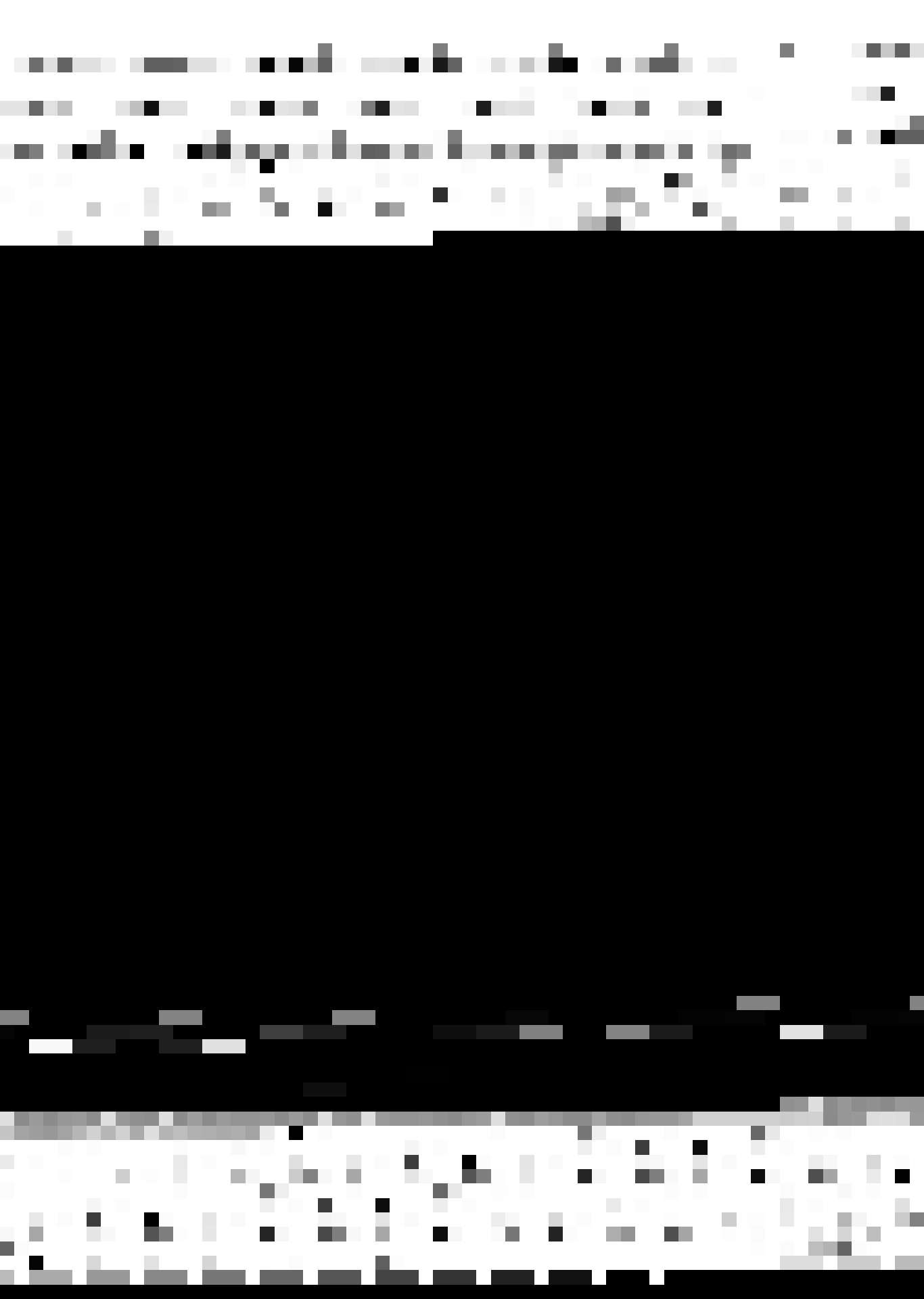
4. Remarkable graphitization is observed on the surface of diamond when heated in powder of Fe and Mn [10].

5. Numerous small dents are observed on the surface of diamond heated in respective powders of Al, Ca, Ti, Cr, Co and Ni.

6. Unexpected thermal erosion is clearly observed on the surface of diamond heated in powders of Pb and Bi.

7. Although no change of  $W_a / W_c$  is presented up to  $950^{\circ}\text{C}$  in the wetting of Sn to the surface of diamond evaporated with respective metals of Ti, Mn, Cu, Ag, Sn remarkably react with diamond [14].

8. Drastic changes of  $W_a / W_c$  are presented in the wetting of Sn to the surface of diamond evaporated with the respective metals of Cr, Fe, Co and Ni. Sn flows on the evaporated surface of diamond with Co and



adheres strongly.

9. Thermal erosion of diamond heated in powder of pure metal has not only close correlation with the wetting of evaporated diamond, but also may give the strategy for the improvement of the wettability by metals and the better understanding of diamond for metals.

10. Titanium is a strong carbide forming element and reacts vigorously with diamond to form  $TiC$ . A reduction of angle of contact is observed on addition of Ti to Cu. For alloys containing 5 wt% Ti, the values of the angle of contact ranged between  $100-120^\circ$  and  $10-30^\circ$ . It was only at Ti contents of 10-15 wt%, that complete spreading of Cu was observe. These undesirable effects disappeared on addition of Sn (5-10 wt%) to Cu. Ti markedly increase the work of adhesion of Sn to Ti and consequently decreases the angle of contact between diamond and molten Sn. A similar effect by titanium on the spreading of bronze on diamond is also observed [15].

## 2.4 SUPERABRASIVE BONDS

### 2.4.1 Primary Functions Of The Bonds

The primary function of the bond is to hold the abrasive grits during grinding process. The bond should ideally fulfill the following functions:

1. Adequate grit retention, to ensure proper grit action, without premature pull out from the surface of the rim.
2. Controlled bond erosion, leading to gradual exposure of new cutting points.
3. Adapted mechanical characteristics to ensure optimal transfer of the grinding forces from machine to work piece.



4. Adequate dissipation of the heat generated by the action of the grits on the work piece, and by the friction of chips and work piece against the rim.

#### **2.4.2 Mechanical Properties Of Bond Vs Wheel Perform**

Grit friability and grit retention by the bond are the two most important factors at the grinding interface. Both of them play a leading role in determining the grinding behaviour at the microscopic level. Although the bond itself, as a material defined by its composition and its manufacturing process possesses measurable macroscopic mechanical properties such as indentation hardness, rupture strength and modulus of elasticity, no direct correlation has ever been found between wheel life and its performance, and bulk mechanical properties. This does not come as a surprise since conventional bulk mechanical properties are measured in a near-equilibrium state in no way comparable to the situation which a grit is exposed to dynamically, during its useful grinding lifetime on the rim's surface.

Table 2.2 gives representative values of bulk mechanical properties for major bond types. As one moves from resin to vitrified and metal bonds, the Brinell Hardness goes through a maximum, while rupture strength and elasticity increases monotonously. Each of the bonds within one bond type was developed in response to a specific application. Table 2.3 gives the contrast between conventional and superabrasive grinding wheels.

#### **2.4.3 Difference With Respect To Conventional Wheel**

Significant differences cleave conventional from superabrasive wheels. A major difference centers around the actual volume of abrasive material available. While conventional wheels can be bulky, with volumes

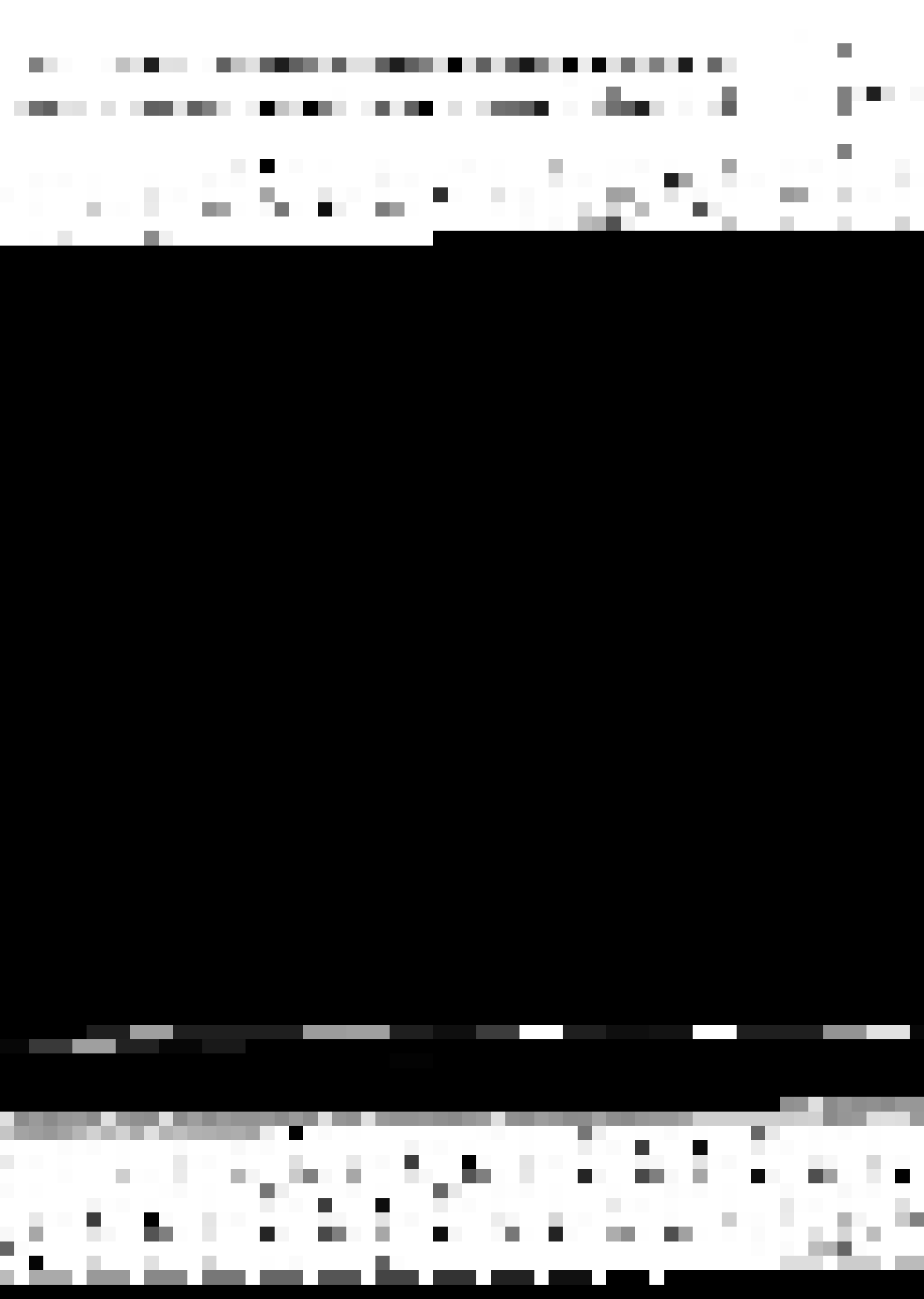


Table 2.2 Bulk mechanical properties for the three major bond types.

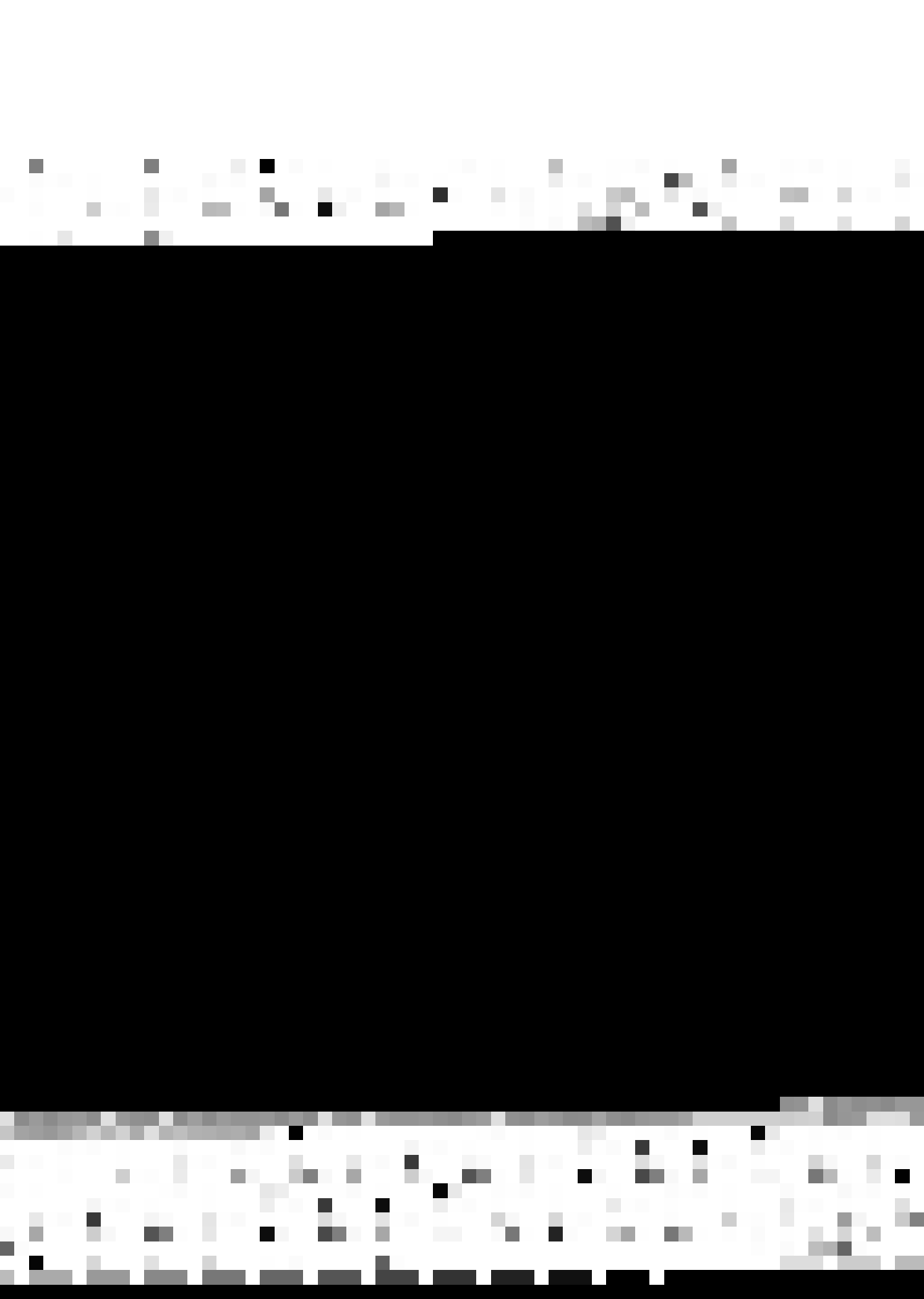
Mechanical property	Resin bond (B-55)	Vitrified bond (V-CR)	Metallic bond (M-263)
Brinell hardness (kg/mm <sup>2</sup> )	228	380	278
Rupture strength (kg/cm <sup>2</sup> )	1 046	1 243	2 073
Modulus of elasticity (kg/cm <sup>2</sup> )	173 500	599 500	792 000

The three Superfix bonds were selected from the standard product range offered by Diametal AG, CH-2500 Biel, Switzerland.

Table 2.3 Contrasts between conventional and superabrasive grinding wheels.

Property/characteristics	Conventional wheels	Superabrasive wheels
Volume of abrasive material, respectively of abrasive rim	<i>Large:</i> a typical peripheral wheel will have the following dimensions $\phi 300 \times 20 \times \phi 127$ and a volume of 1160 cm <sup>3</sup> (180 in <sup>3</sup> )	<i>Small:</i> a typical peripheral wheel will have rim dimensions of $\phi 300 \times 8 \times 4$ , i.e. a rim volume of 30 cm <sup>3</sup> (4.6 in <sup>3</sup> )
Hardness difference between abrasive and workpiece	<i>Small:</i> typically several hundred to at most 1500 Knoop units, as for example for the pair aluminium oxide/high speed steel	<i>Large:</i> typically several thousand Knoop units for diamond v. carbide
Components and component proportions in abrasive material	<ul style="list-style-type: none"> <li>– Mostly abrasive (40–90% by volume)</li> <li>– Low proportions of binder (5–20% by volume)</li> <li>– Small to substantial proportions of pores, depending on wheel structure (20–60% by volume)</li> </ul>	<ul style="list-style-type: none"> <li>– 10 to 25% by volume of abrasive only</li> <li>– varying amounts of binder, filler, lubricant and/or porosity</li> </ul>
Manufacturing process	Cold pressing of abrasive material followed by firing in kilns without any pressure application; <i>lengthy</i> procedure (temperature gradients in bulk)	Sintering usually with simultaneous application of temperature and pressure; <i>rapid</i> procedure (smaller volumes involved)





of the order of  $1000 \text{ cm}^3$  or more, superabrasive wheels have rim volumes from a fractions of a  $\text{cm}^3$  to at most  $50 \text{ cm}^3$ . The contrast between conventional and superabrasive wheels is even more striking if one takes a look at Fig 2.7. From the figure, it can be seen that the thin rim of the superabrasive wheel (bottom half) is with at most 20 vol% of abrasive and the balance is constituted by binder and filler. The conventional wheel (top half) is made up of large pores separated by bridges constituted by abrasive grits held together by small amount of binder. The difference in Knoop indentation hardness between abrasive and work piece is smaller in the case of conventional wheels. Hence a much faster grit wear than in the case of superabrasive wheels. Whereas, in a first order approximation, a conventional grinding wheel is made up almost entirely of abrasive grits and pores, the rim of a superabrasive wheel consists usually of 1/5 in volume of abrasive grit, the remainder being made of varying proportions of filler and binder. The manufacturing procedures used for conventional and superabrasive wheels differ with respect to duration of the sintering process and to the timing followed for the application of pressure and temperature.

#### 2.4.4 Bond Types

Three of the four bond types available today derive their name from the binder material, i.e. the bond component responsible for the cohesion of the rim viewed as a macroscopic unit and for grit retention during grinding, to wit the resin (B), metal (M) and vitrified bonds (V). Common to all three is the fact that during sintering process, the bonding agent becomes fluid and wets to some degree all the other components present in the rim. The bonding agent is some form of synthetic polymer or resin in the case of resin bonds, a metal or most usually a metallic alloy



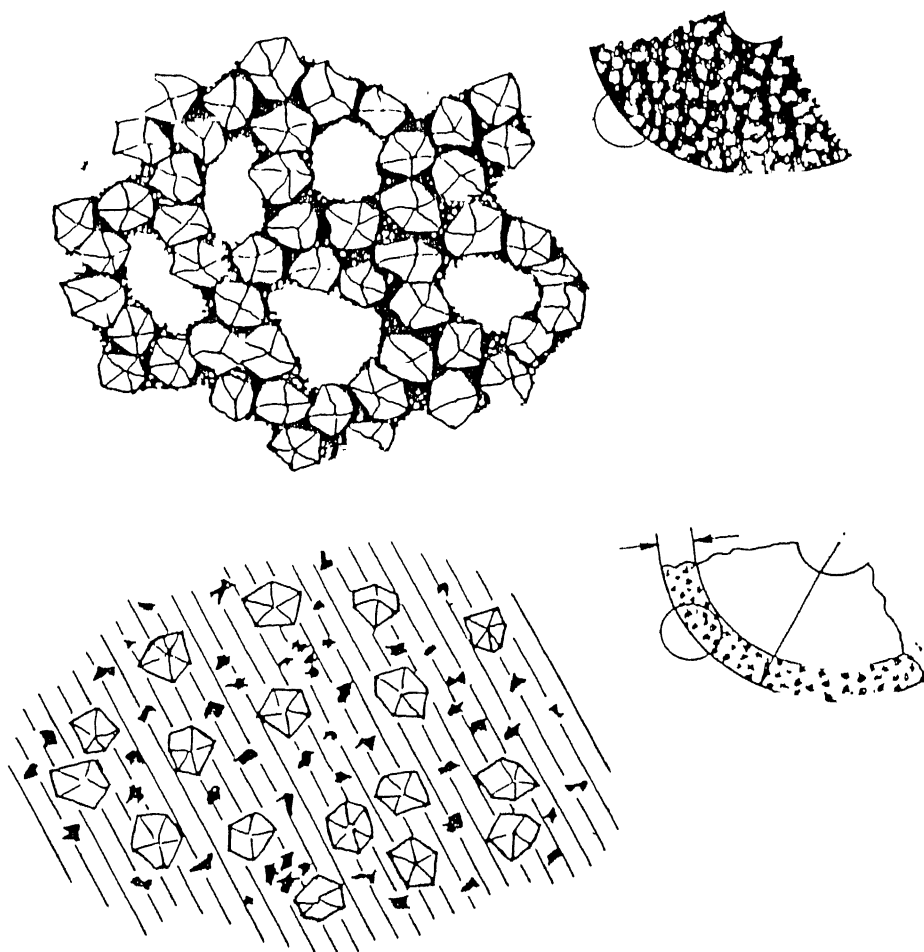
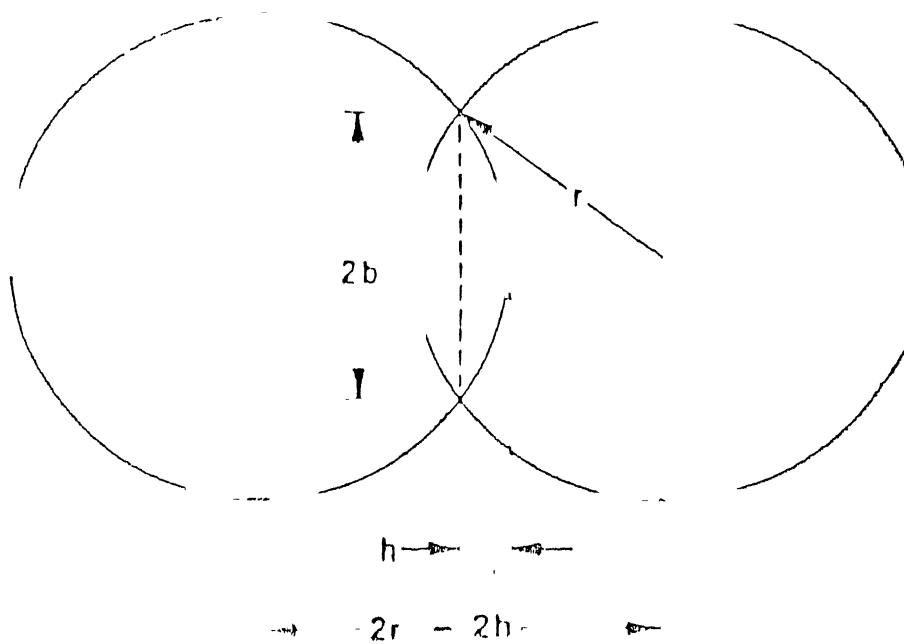


Fig 2.7 The contrast between conventional and superabrasive wheels





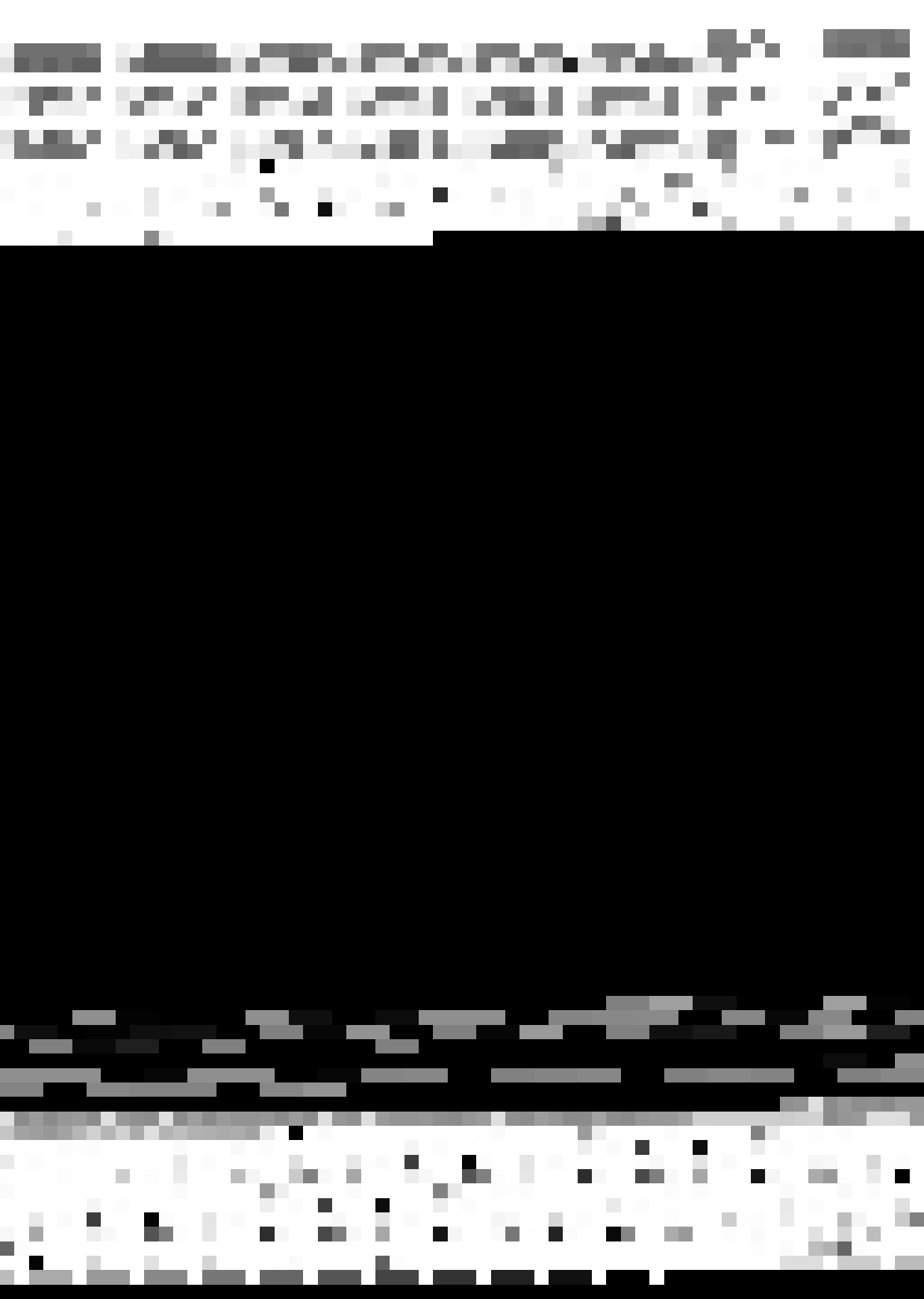
in the case of metal bonds, and a glass or ceramic in the case of vitrified bonds. The fourth type available, the electroplated bond, forms a separate group and reduces to two components, the electroplated nickel layer into which the other component, i.e. the abrasive grit, is trapped [9].

#### 2.4.4.1. Resin Bond

The resin bond has a paramount importance in the grinding of WC, where a good balance between wheel life and removal rate is required. Resin bonded wheels are free cutting and easy to use in a wide range of conditions. Resin bonds contain a polycrystalline, low strength, metal clad diamond grit, allowing efficient self-sharpening via partial fragmentation. The grinding forces remain relatively low, which means that resin bonds can also be used on unstable or older machine, without the risk of chatter or vibration.

#### 2.4.4.2. Metal Bond

Metal bonds hold the strong blocky monocrystalline grit more firmly than resin bonds. During sintering, the metallic binder, usually some bronze alloy, softens and wets the diamond grits present. The excellent grit retention, and the high abrasive wear resistance of a metallic phase, yield 'hard' acting wheels adapted to form grinding and to such brittle materials as glass, ceramics and other hard, non-metallic work pieces. Sustained self-sharpening is only possible under substantially higher grinding forces than those encountered while grinding with resin bonds. Hence, the necessity of using, in most cases, flood coolant to avoid thermal damage to grit and work piece. The fact that most metal bonds contain porosity in the form of graphite filler, points to the major drawback of metal bonds, i.e. the rather limited removal rate linked to high grit considered 'a priori' as great advantages, limit the performance



of metal bonds. The grinding pressures necessary for sustained self-sharpening are only compatible with stable, rigid machines, not likely to be readily induced to chatter.

Metal bonds employ the techniques of powder metallurgy, using elemental or pre-alloyed metal powders. A further disadvantage with respect to resin bonds is the higher sintering temperature necessary to melt the metallic phase, which results in higher manufacturing costs. Metal bonds can be used dry only in the case of very small contact areas, as on optical grinding machines, or profile copying machines, where shape stability and not removal rate is paramount [16]. In these applications, the wheel touches the work piece intermittently and cools off during the inactive period. A grinding ratio is defined by the ratio between the stock removal of the work piece and the wear of grinding wheel is one of the indices of the evaluating the grindability. Metal bond shows a larger grinding ratio than resin bond wheel because the grains are more strongly held by the bonding materials [17].

#### 2.4.4.3. Vitrified Bond

Wheels with vitrified bonds combine to some extent at least the freeness of cut characteristic of resin bonds with the wear resistance of metal bonds. Glass being a major component of such bonds, the resulting rim, even with the addition of fillers such as graphite or copper, is heat sensitive and brittle.

#### 2.4.4.4. Electroplated Bond

In this case the rim reduces to a superficial layer of diamond grit held in place by a nickel layer acting as bonding material. A major application is the profile grinding of WC form tools [9].

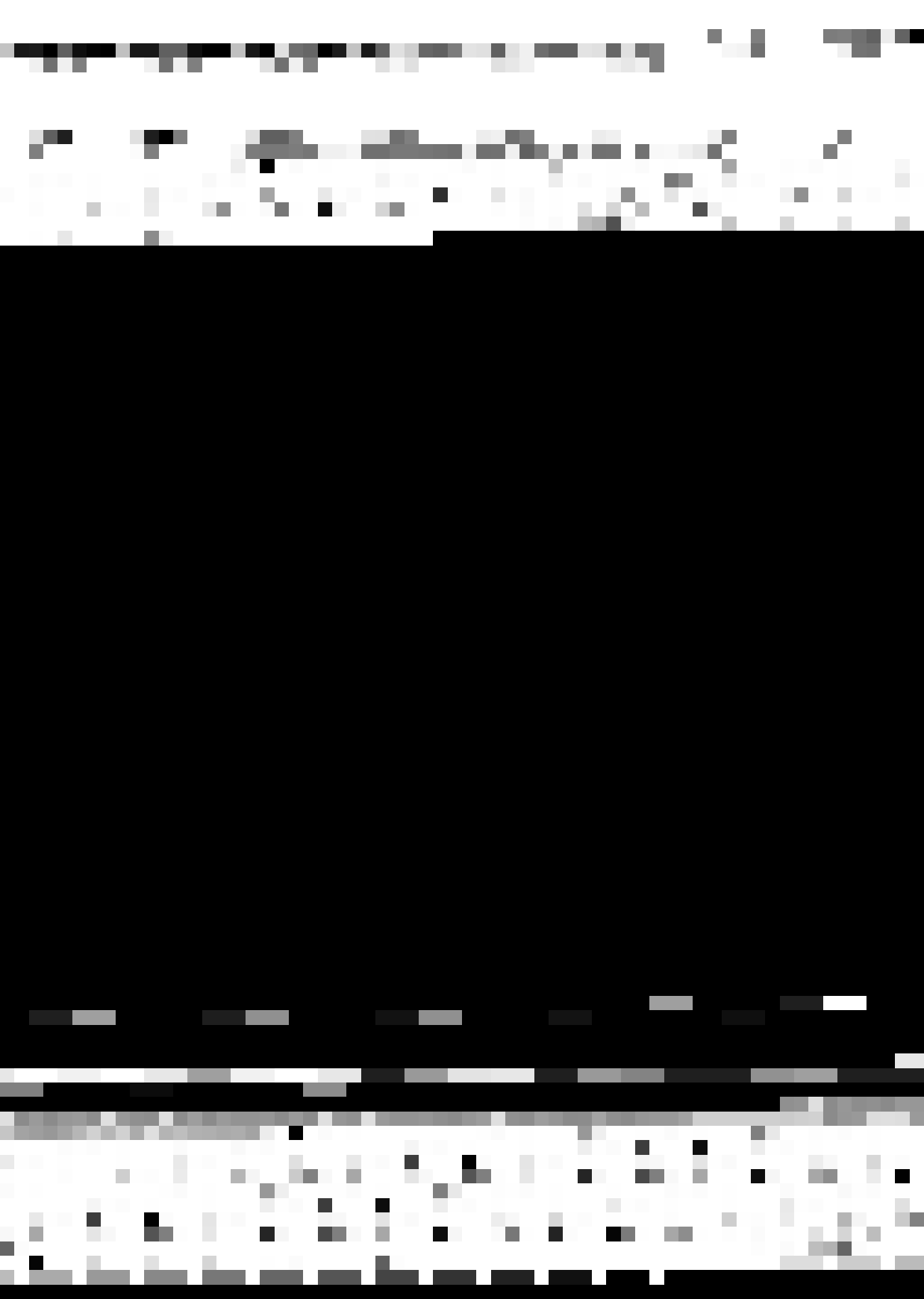




## 2.5 SINTERING BEHAVIOUR OF DIAMOND DISPERSED METAL MATRIX COMPOSITES

Diamond powders can be sintered into strong masses at high temperature and pressure in a matrix which acts as a bonding material. Most of the desirable physical properties of the sintered masses, such as hardness and thermal conductivity, approach those of large single crystal, their resistance to wear and catastrophic splitting is superior. The sintered masses are produced on a commercial scale and are increasingly used as cutting tools on hard or abrasive materials, as wire drawing dies, in rock drills, and in special high pressure apparatus. The advantages of a strong, polycrystalline mass after sintering are its greater "toughness" (the easy cleavage planes of its component crystals lie randomly toward one another, so that propagation of a crack throughout the mass is difficult) and its more uniform wear, independent of direction. Such masses lack the aesthetic appearance of single crystals but their greater utility makes efforts to prepare them worthwhile [18].

By sintering one means the bonding together of a mass of small into a larger, coherent piece. During this process the contact patches between particles grow and the total volume of the mass shrinks. Eventually the mass becomes sufficiently dense and strong even though some voids may remain. As a simple model of a sintered mass, consider a face centered cubic array of close packed spheres, each of radius  $r$ , which have a common circular contact patches of radius  $b$ , and center to center distances of  $2r-2h$ , and this is shown in Fig 2.8. Then a cap of volume  $(3r-h)\pi h^2/3$  is missing from each sphere. A unit cell, of edge length  $a = 2\sqrt{2}(r-h)$ , contains four spheres, each with 12 nearest neighbors. Then  $F$ , the actual volume fraction of the cell occupied by spheres will be



$$F = \frac{4 [4\pi r^3 / 3 - 12 (3r-h)\pi h^2 / 3]}{16\sqrt{2} (r-h)^3} \quad (2.2)$$

When the spheres are flattened so that the contact patches from six coplanar spheres touch, the voids between spheres will no longer be connected. This occurs for  $2(r-h) = \sqrt{3} r$  or  $h/r = 0.134$ . The total contact patch area,  $C$ , per unit cell, arises from 12 patches on each of the four spheres, or 24 net patches, each of area  $\pi b^2$ , so that

$$C = 24 \pi b^2 = 24 \pi h (2r-h) \quad (2.3)$$

For mechanical strength and transmission of heat, one considers the ratio  $c/a^2 = M$ . Table 2.4 shows that  $M$  increases rapidly at higher values of  $F$ . A practical lower limit for carrying most of the strength of the grains might be  $M = 2$ , where  $F$  is 0.92. Foreign material among the spheres will be trapped when  $F$  exceeds 0.962 [18].

The driving forces for sintering are decrease in free energy accompanying reduction of stresses and surface area. Pure material sinter reasonably rapidly at absolute temperature about 0.6-0.7 that of melting. Solvent impurities may assist sintering but they may also affect the sinter mass undesirably. The embedding of diamond particles in some kind of tough matrix (usually metal) to form a hard composite mass is satisfactory for many uses of diamond, but is not a substitute for direct sintering between diamond grains when the properties necessary for a cutting tools, such as high hot strength and good thermal conductivity, are desired. Sometimes the conductivity, strength, stiffness, hot hardness and thermal expansion of possible matrix materials are so inferior to those of diamond that the properties of the composite tend more to those of the matrix than of diamond [19].

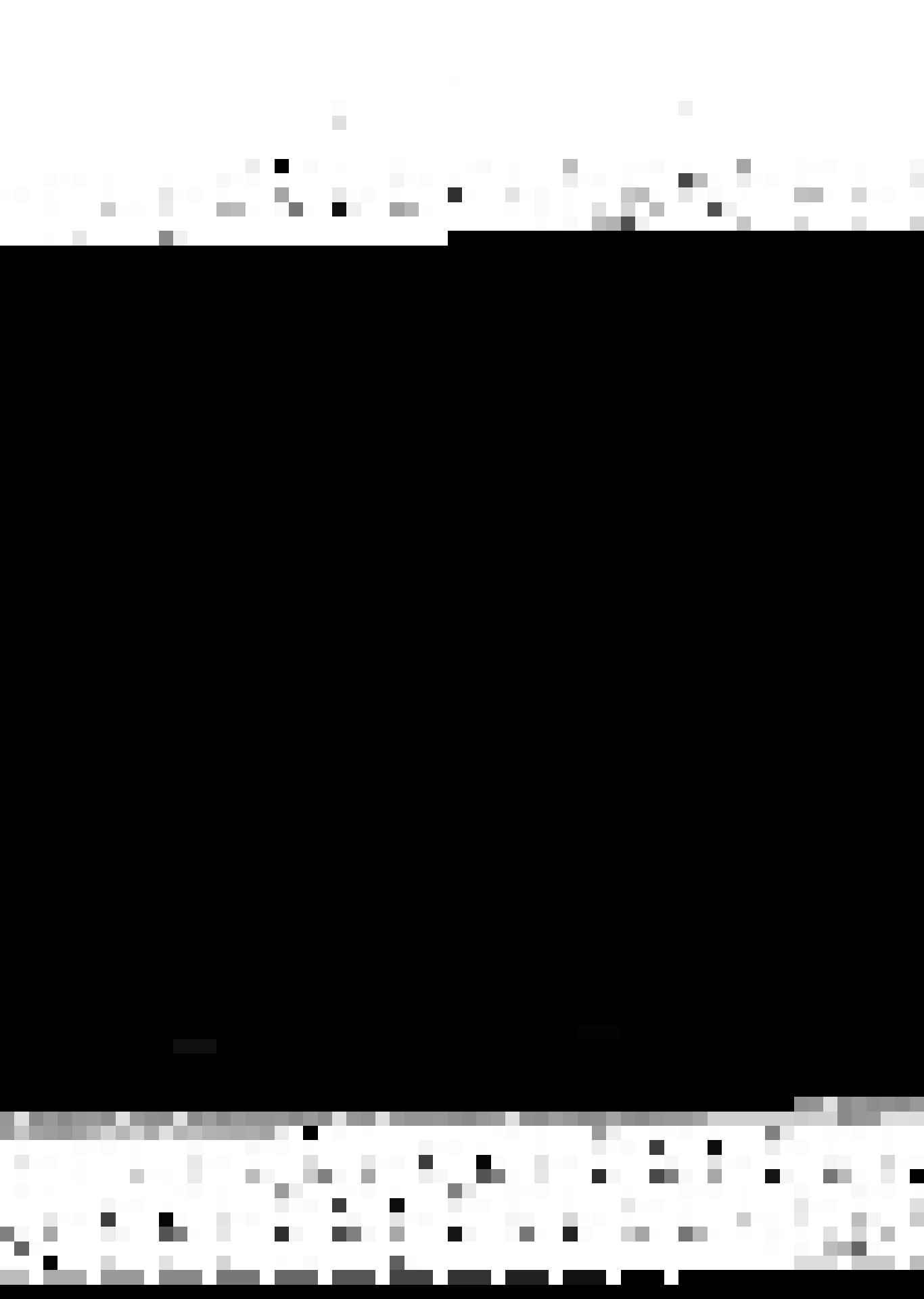
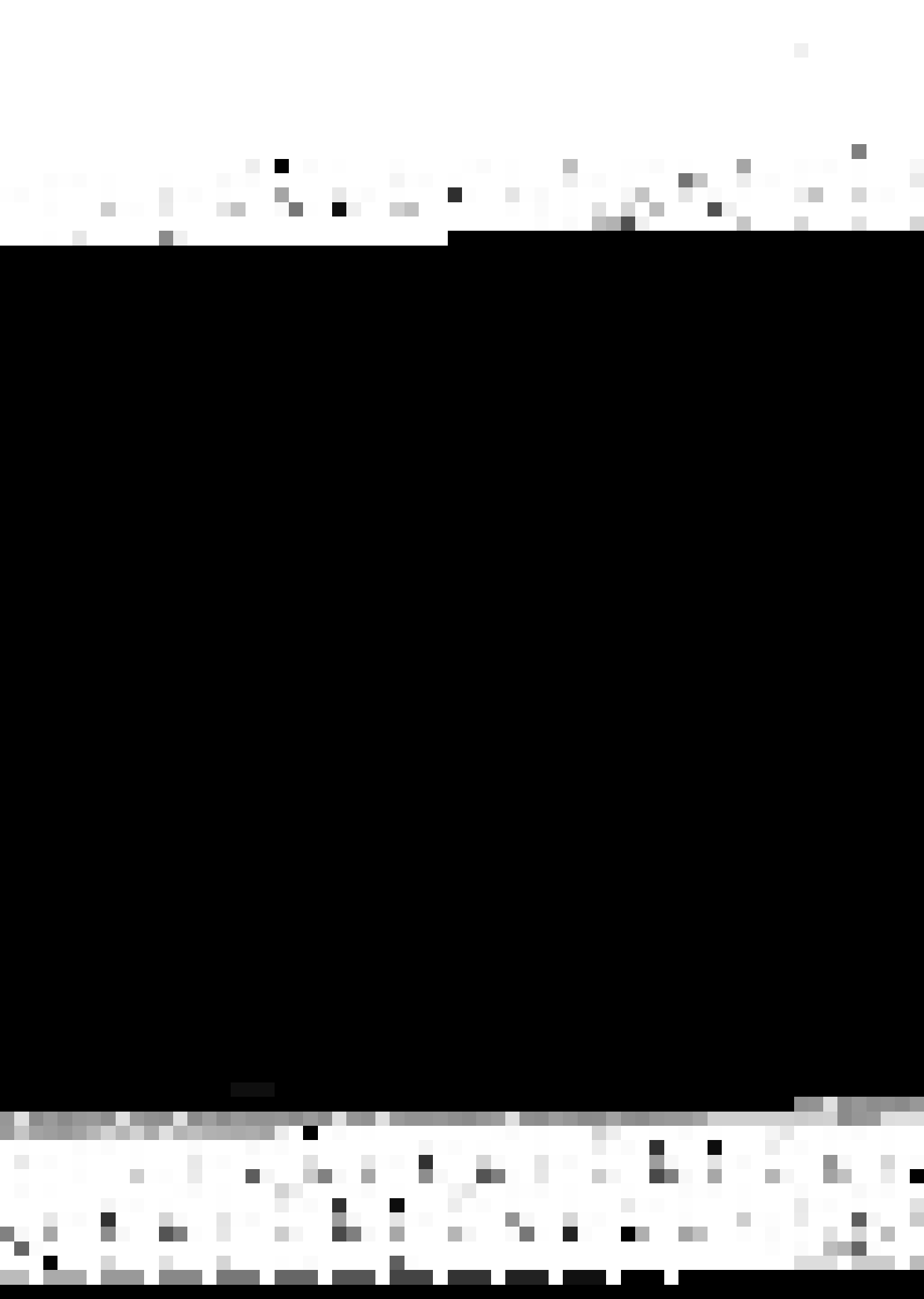


Table 2.4 Values of  $F$  and  $M$  for various values of  $h/r$  up to 0.134 above which the analysis is irrelevant.

		Values of $h/r$						
		0	0.04	0.06	0.08	0.10	0.12	0.134
$F$		0.704	0.826	0.863	0.895	0.927	0.953	0.962
$M$		0	0.801	1.242	1.715	2.21	2.75	3.14

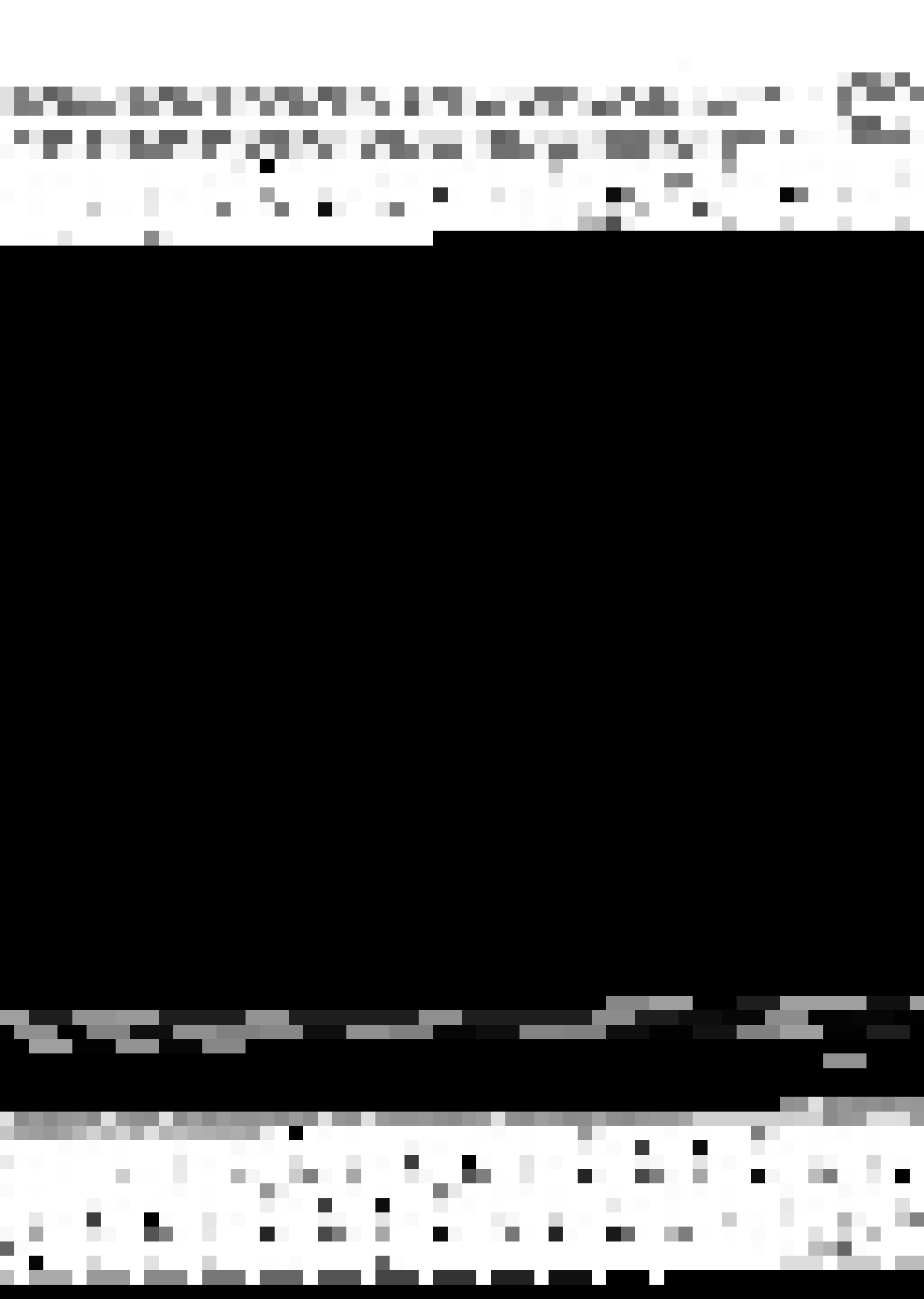


The melting point of diamond is about 1000 K, so that a suitable sintering temperature would be about 2700 K, about the same temperature as that used in the manufacture of graphite from coke. The required pressure for diamond stability would be about 70 Kbars. These conditions are difficult to achieve in laboratory conditions and thus it becomes necessary to sinter diamond particle in some sort of matrix.

Hardness of diamond is a practical obstacle to achieve the above mentioned pressure over the entire surfaces of all the consolidating particles. A vessel into which diamond grains are poured may contain about 30 % voids, depending on the grain shape and size distribution. Squeezing the vessel scarcely affects the void fraction because the hard particles do not crush mechanically, instead they indent the walls of the vessel. When the diamond particles touch each other, local pressures are very high in the range of 300 to 1000 Kbar. In other places, the local pressure is that of voids. At an average pressure of, say, 70 Kbar on the vessel, one has heavily indented vessel walls, and a network of relatively low pressure. As the sintering temperature is reached, some reduction in strength and hence local pressure will occur, and the contact patch will increase slightly. At 2400 K the transformation to graphite is rapid at low pressures. One volume of diamond expands to about 1.6 volume of graphite until the local graphite pressure is high enough to repress further graphite formation.

The presence of solvent catalyst metals, such as Mn, Fe or Ni facilitates the transformation between diamond and graphite [20]. These molten metals are excellent solvents for most other metals and their carbides and hence might be expected to attack the walls of the vessels containing the mass to be sintered. Too much metal among the diamond grains reduces the stress gradients that can drive the consolidation





process. Fig 2.9 shows the photomicrograph of man made sintered diamond mass.

Another difficulty that occurs with a mixture of catalyst metal and diamond is the formation of stable arches or shells before the entire mass is consolidated. Such a shell is essentially all diamond in perfect mechanical contact and hence changes shape very slowly. Inside it the pressure falls to that of diamond-graphite equilibrium; no consolidation occurs and graphite may form from diamond there. Suitable vessel design consequently eliminate this problem, thereby reducing the overall pressure required for consolidation. Finally, if one considers a mass of sintered diamond embedded in a pressure transmitting medium at high pressure. This medium is necessarily a solid at the low temperature (20-200°C) prevailing during the reduction of pressure to 1 atm. Since nothing expands so little as diamond during pressure reduction, the outer surface of the sintered diamond mass are exposed to strong tensile stresses as the pressure transmitting medium tries to expand more rapidly. These stresses can be high enough to tear the sintered mass apart if it is not strong enough or convex enough.

From the above discussion, it can be said that the production of sintered superhard materials is beset with several peculiar and difficult problems. Infact, they blocked the development of practical production of sintered diamond bodies for many years despite numerous attempts and much experimentation in many laboratories [20].

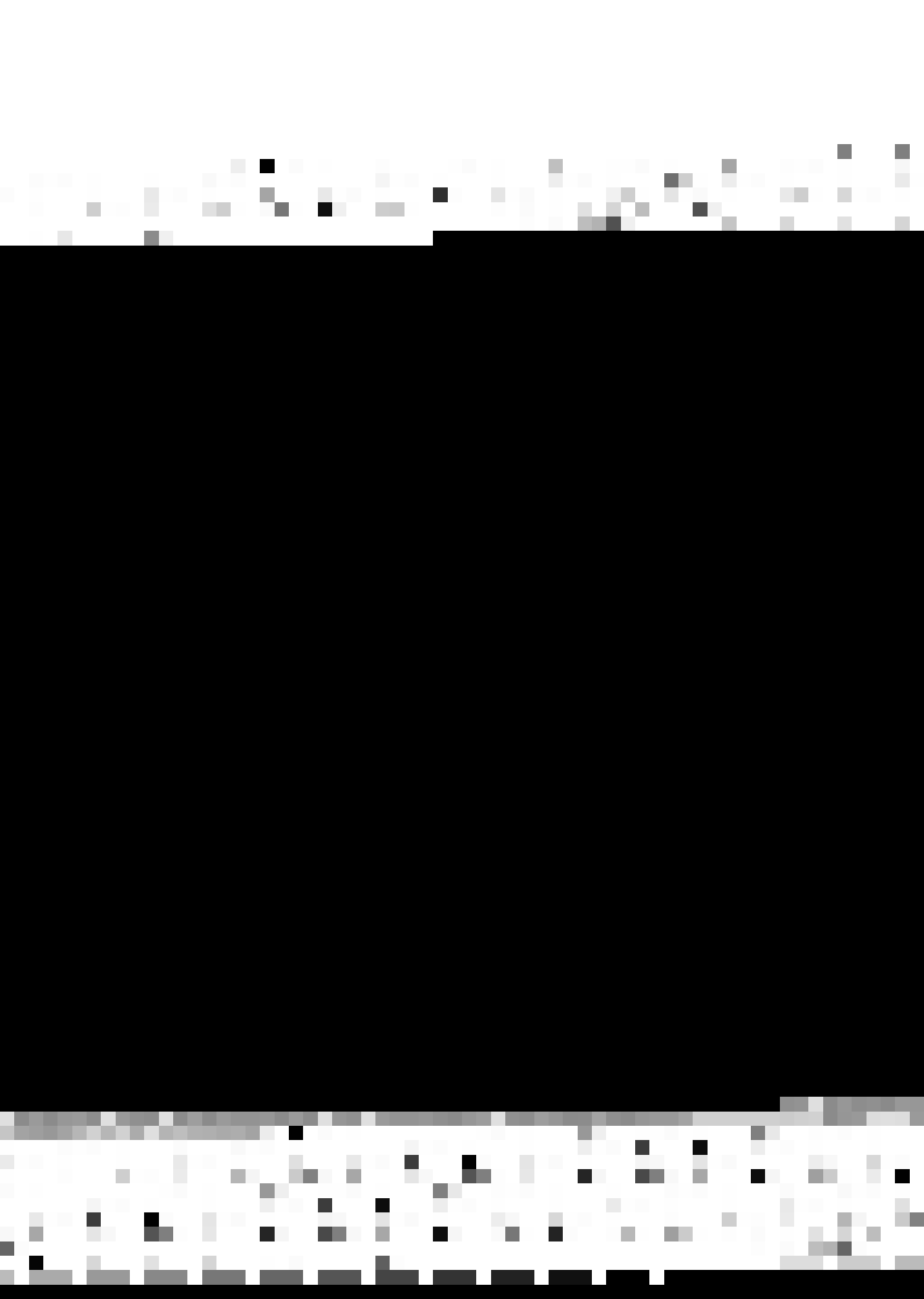
### **2.5.1 Progress Toward Practical Solution**

The availability of apparatus capable of maintaining temperature of 1500 to 2000 K together with pressures of 50-70 Kbar, where diamond is stable, fostered new work on sintering diamond. Katzman and Libby [21]





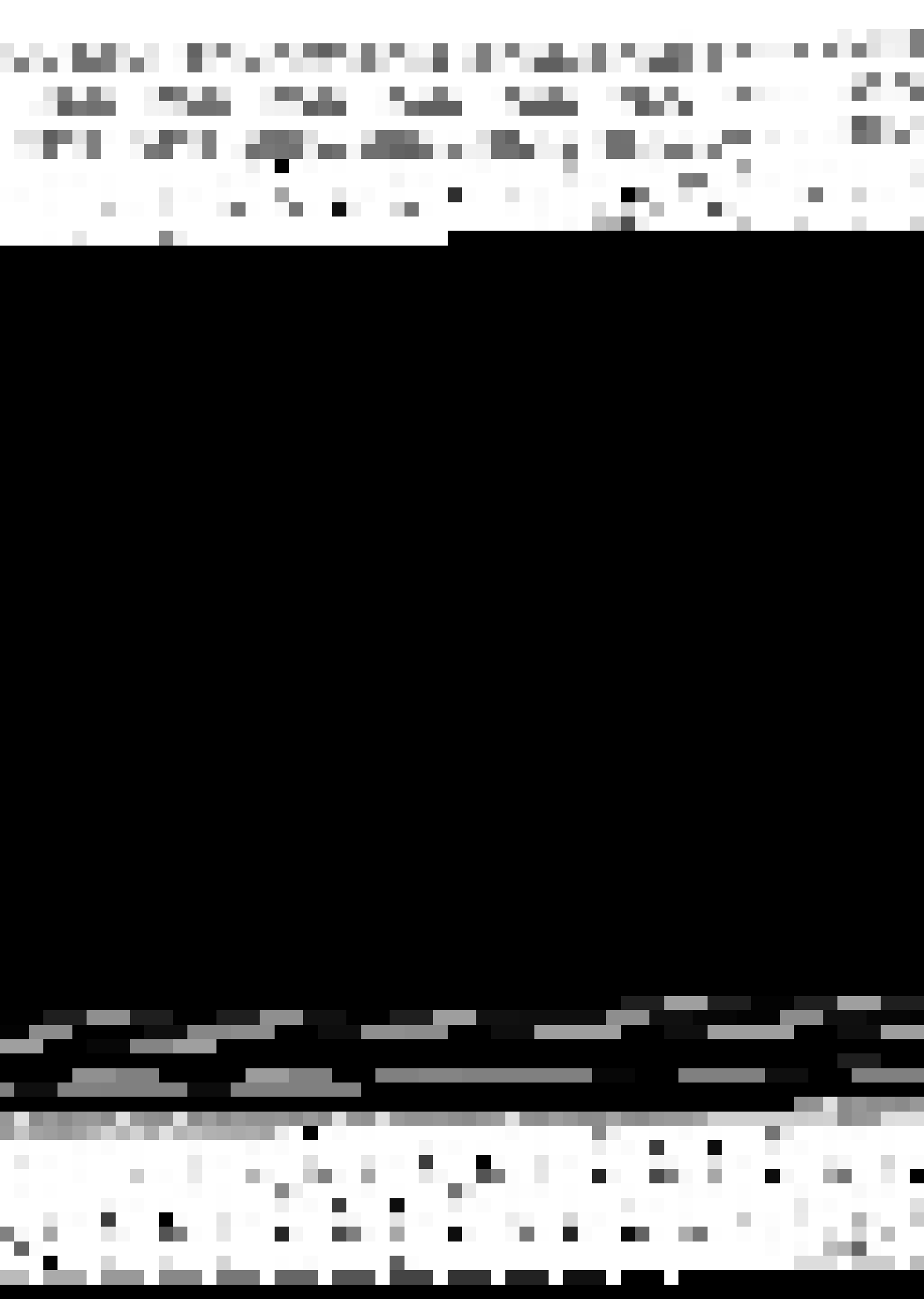
Fig 2.9 Photomicrograph of man made sintered diamond mass



described the formation of sintered diamond compacts with cobalt binder. They found the best conditions to be about 20 min at  $1600^{\circ}\text{C}$  and 62 Kbar using a mixture of cobalt and diamond powders (20:80, by volume) of particle sizes of 1 to 5  $\mu\text{m}$  held in a tantalum vessel. The sintered masses were about 6 mm in diameter and 3-8 mm long. There appeared to be some grain growth due to diamond-diamond bonding. The masses had about half the life of single crystal diamond when used to dress abrasive wheels. The process never reached commercial production.

Stromberg and Stevens [22] reported on the sintering of diamond at  $1800^{\circ}\text{C}$  to  $1900^{\circ}\text{C}$  and 60-65 Kbar. They loaded cleaned natural diamond powder of sizes 0.1 to 10  $\mu\text{m}$  into tantalum containers. The vessels, about 3 mm in size, were heated in vacuum to remove gases and then sealed by electron beam welds before being loaded into a high pressure apparatus and exposed to high pressure and temperature for about an hour. In some experiments about 1% of boron, silicon or beryllium powder was added to react with residual gases and form strong carbides for bonding. An indium sheath surrounding the vessel helped prevent tearing apart of the mass as the pressure was reduced. The diamond masses obtained had densities of up to 99% and micro hardness of 75-90% that of solid diamond. Efficient mixing of diamond particles in a range of sizes suitable for high packing density produced the highest final densities. No tests of strength or wear resistance were reported.

Hall [23] found that strong diamond compacts could be made at about 2000 to 2500 K and 65 Kbar using short sintering times of 20-200 seconds. The diamond powder is contained in graphite tubes and no special cleaning procedures are mentioned. The products are usually black cylinders with densities of about  $3.2 \text{ gms/cm}^3$ . Extra bonding agents (borides, nitrides, carbides and oxides) may be added to the diamond before



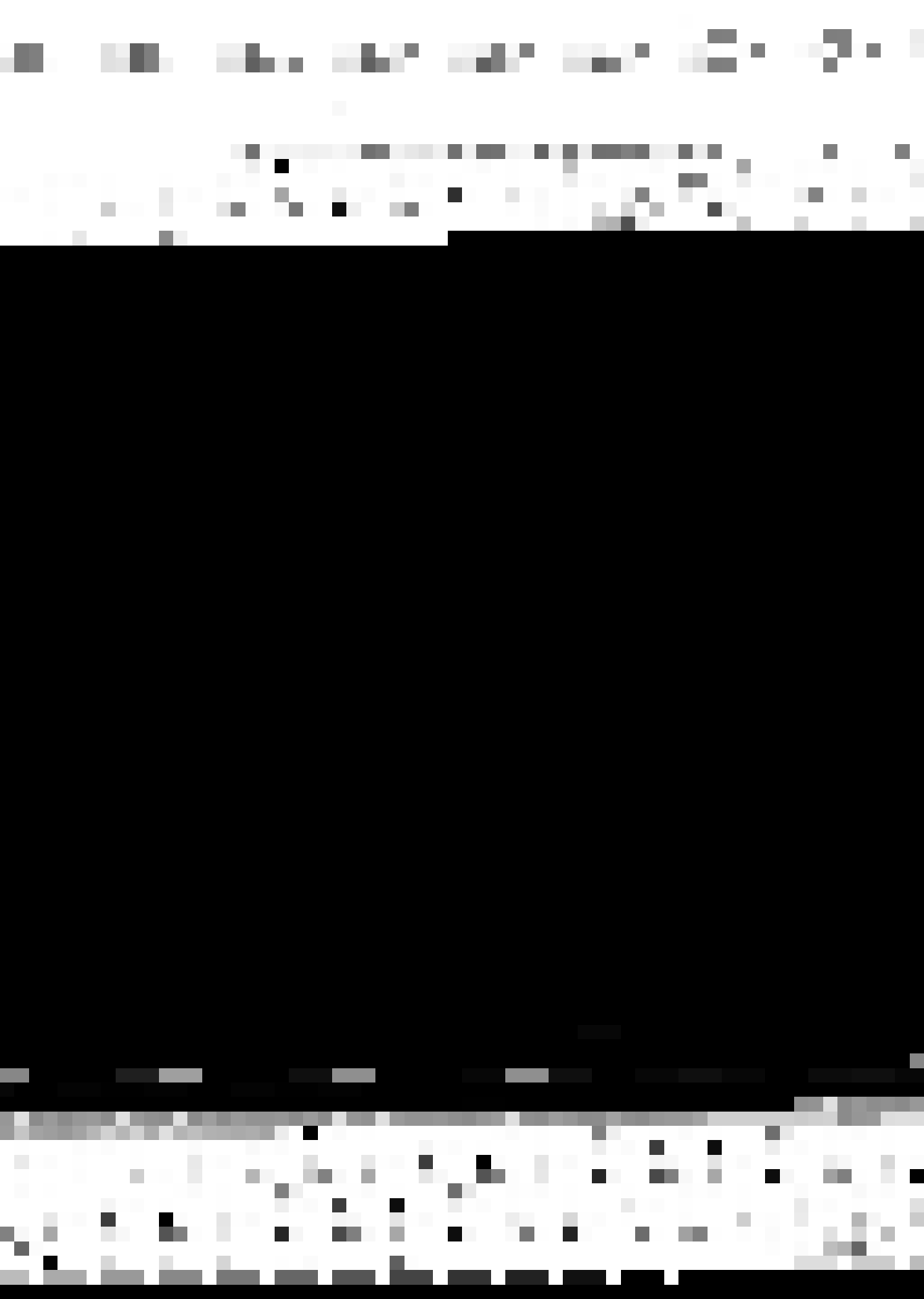
sintering such diamond compacts are available and have found uses as cutting and dressing tools and as gauge blocks.

Hibbs and Wentorf [24] described commercially available diamond compacts and some of their uses in cutting and shaping hard materials. These sintered masses are characterized by extensive direct bonding between the hard particles and a minimum of second phase. Temperature in the range of 1500-2000°C are suitable for their formation and these temperature requires pressures of the order of 50-70 Kbar so that cubic crystals are thermodynamically stable during sintering. The grain size in the diamond compacts can range from a few to several hundred micrometers in size. Smaller grain sizes permit finer cutting edges on the finished tool. Usually the hard materials are consolidated as a layer about 0.5 mm thick on the circular face of, or as a case within, a cylinder of cobalt-cemented WC which provides strength and convenience in use. Cutting tool blanks are commercially available in disks up to about 14 mm in diameter and wire drawing die blanks of comparable sizes are also available. The General Electric Company has been manufacturing sintered diamond materials since 1972, and these materials enjoy wide utility and acceptance for many industrial purposes, where they replace not only large single crystal but also often other hard sintered material such as WC and  $\text{Al}_2\text{O}_3$ .

### 2.5.2 Relation Of Microstructure To Property

Although sintered superhard materials are relatively new, some understanding of the microstructure features and their relation to macroscopic properties has been developed. The stronger and more successful man-made sintered diamond compacts are brittle second phase materials, predominantly randomly oriented diamond (> 90% by vol) with the remainder a metallic phase. The modulus of elasticity of the second phase





composite was found to be 890 G Pa [25], which approaches that of single crystal. When the metal phase was dissolved away, the modulus of polycrystalline diamond, corrected for porosity was 840 GPa. The pores were uniformly distributed and were less than 1  $\mu\text{m}$  in diameter. This result strongly suggest that there is diamond-diamond bonding in the composite and that the metallic phase is a minor contributor to the strength of the material acting only as a mechanical filler. Besides this indirect evidence, there is convincing direct support for diamond-diamond bonding from microscopic observations of grain boundaries.

Another prominent microstructural feature of some sintered diamond is deformation twinning, which is seen as group of lines within grains. When diamond is deformed under condition that inhibit brittle fracture, it can deform by twinning on (111) planes. The deformation twins within grains are visible because of relief polishing which emphasizes the greater wear resistance of the twinned region compared to the rest of the crystal. If the pressure-temperature conditions are adequate, this type of deformation structure can be expected when the diamond grains are large enough to sustain such deformation, and this microstructural feature may be significant in grains that are less than about 1 micrometer in size. In addition, under semi hydrostatic conditions, as might exist with the pressure of a softer phase, the deformation structure will probably not be generated everywhere in the compacted aggregate.

## 2.6 MANUFACTURE OF DIAMOND DISPERSED METAL MATRIX COMPOSITE TOOLS BY ROLLING OF POWDERS

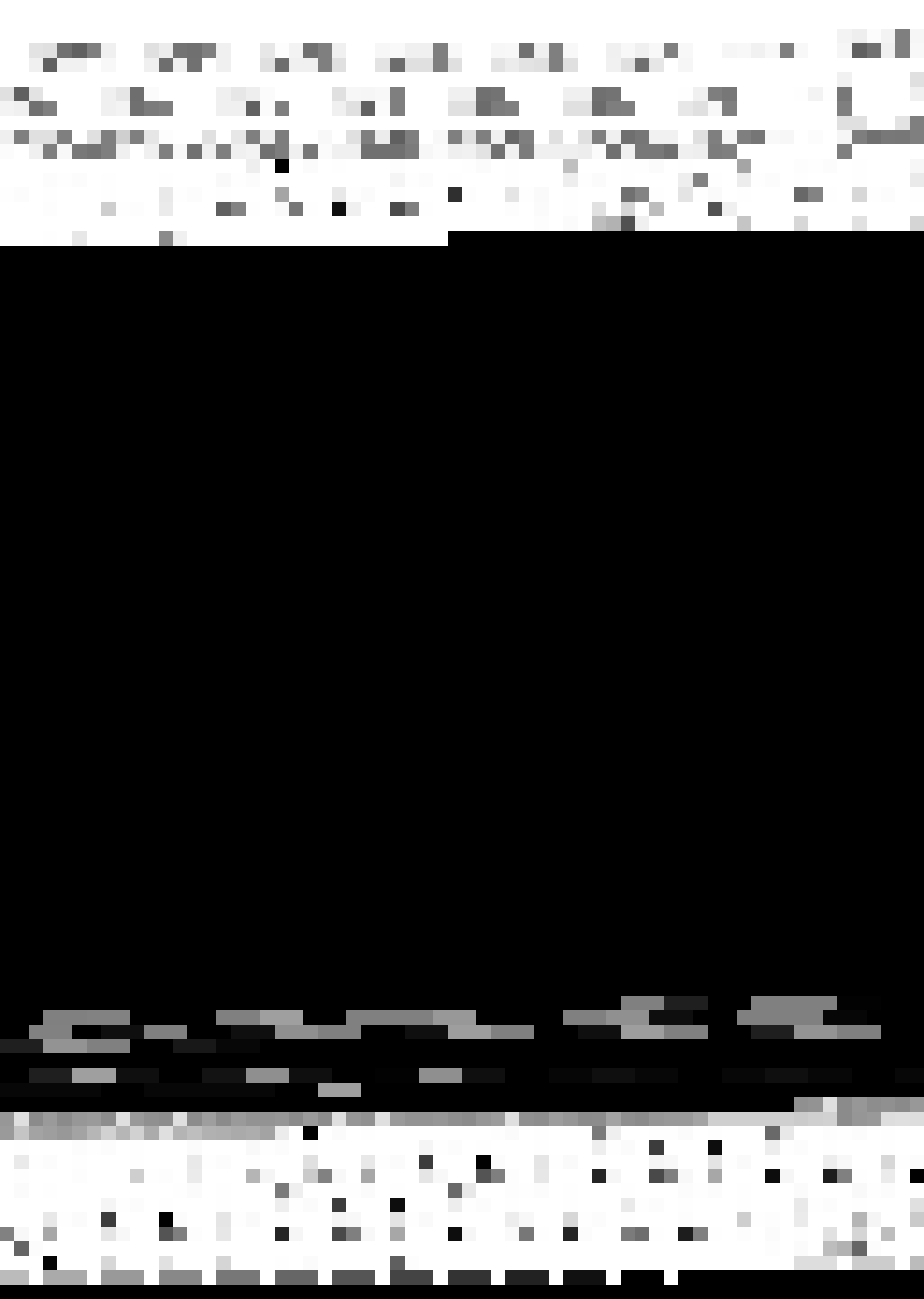
Today diamond tools produced by rolling diamond-containing powder mixtures which are finding increasing applications in the machining of



various materials. The strength of such tools is markedly affected by their diamond filler. Rolling of metal and diamond is employed when diamond tools of small thickness are desired. Several trends are noted now-a-days in the manufacture of abrasive diamond tools by utilization of the technique of rolling metal powders. The first trend is the manufacture of a tool with a large working surface (over  $100\text{ cm}^2$ ) at a relatively small thickness (not more than 1-4 mm). Only application of the process of rolling of powders enables us to achieve the required uniform density across the entire tool surface.

The second trend is the tendency to replace the operation of hot compression by hot or warm rolling to set free the extensive stock of equipment needed for the manufacture of hot compression molds. Very promising is the manufacture of a porous half finished material (25-30% pores) by rolling followed by impregnation with more readily melting alloys. One of the most promising ways of improving resistance of diamond tool to wear is to raise the hardness of the binder, which can be done by cold working/rolling.

Tin bronze is now-a-days most extensively used as metallic binder. Bars made of synthetic diamond and a bronze binder are used for drilling apertures in articles manufactured from alloyed and sulphur containing cast iron with HB values up to 250. The resistance of the bronze binder can be increased by alloying with elements such as Ni, Fe, Mo etc., which have higher moduli of elasticity. There exists definite restrictions to alloying the bronze matrix with the above mentioned elements since the sintering temperature in the molds must be raised to above  $750-800^{\circ}\text{C}$  in order that the maximum density of the tool and heat compression of diamond into the binder can be achieved. The rise of the resistance of deformation produced by alloying can be depressed to definite



extent by simultaneous admixture of elements of low melting point. Fundamental improvements of the wear resistance of abrasive diamond tools can evidently be expected from the use of Ni, Co, Fe etc., as binders, which in the annealed state have a hardness 1.5-2.0 times that of copper (the elastic modulus equal about twice the modulus of copper). Transition metals when added to bronze, may improve the wear resistance of an abrasive diamond tool only if one of the important requirements to be met by the tool is fulfilled: strong adhesion of the diamond to the metal binder. For rolling the plasticity of the binder and its capacity of filling up the gaps between the diamond granules are important [26]. If the rolled strip is too porous, it will reduce to a considerable extent the adhesion of the diamonds to the metal matrix causes the diamonds to be prematurely torn away from the matrix. For strong adhesion of diamond to binder matrices consisting of Ni, Fe etc., the temperature of hot compression (rolling) must be raised to 900-1100°C. It has been realised that rolling of powder mixtures with diamond is a reliable method for the manufacture of products with a large working surface and a small thickness. The technique of manufacturing discs and belts from various bronze binders has been worked out. Consequently, powder rolling, which is one of the modern methods in the production of materials from powders, is conquering a position in the manufacture of abrasive diamond tools.

Sorokin [27] studied the effect of A.S.M. synthetic diamond powder additions and strip thickness on the tensile strength of the metal strip. Binder was a powder mixture consisting of 88.5 Cu, 6.5 Sn, 4.0 Ni and 1.0 wt% graphite. Sn-Ni bronzes are precipitation-hardening alloys which can be strengthened by quenching and aging. Thermally strengthened specimens were produced by a process comprising the following operations: rolling of a charge into intermediate annealing; quenching from a



temperature of  $700^{\circ}\text{C}$  consisting of cooling the container with specimens in a stream of humidified air; cold rolling with a reduction of 33 %; aging for 2 hr at a temperature of  $300^{\circ}\text{C}$ . For each experiment five specimens are prepared and tested. They concluded that to obtain a strip of higher strength, it is necessary to employ a finer diamond powder and to lower its concentration. The tensile strength of diamond containing strip is markedly affected by the latter's thickness, falling with decrease in thickness. The reason why the presence of diamond filler and strip thickness influence the strength of metal strip is that, as the amount and grain size of the diamond powder are increased and the strip thickness (cross section) is decreased, the area of contact between the particles of the metallic matrix decreases. The particles of diamond filler without a metal coating may be regarded as pores which weaken the metallic matrix.

Sorokin et al [28] studied the conditions of manufacture of diamond composite strips, ranging in thickness from 20-110  $\mu\text{m}$ . As starting components for the preparation of specimens, electrolytic Cu, atomized Sn, carbonyl Ni, and synthetic diamond powders were employed. The copper powder was additionally reduced for 3 hr at a temperature of  $400^{\circ}\text{C}$  in  $\text{H}_2$  atmosphere.

Procedure consisted of following operations: weighing out of charge components, 6 hr mixing, rolling of blank strips of 25-30 % porosity, 2 hr sintering in  $\text{H}_2$  at  $700\text{--}750^{\circ}\text{C}$  consolidation rolling, cold rolling with intermediate recrystallization annealing, as a result of which strips of required thickness were obtained and thermo mechanical processing. The metallic binder was a Cu-Sn-Ni- alloy with 6.5 wt% Sn, 4-13 wt% Ni. The synthetic diamond powders, varying in grain size from 3-5 to 20-28  $\mu\text{m}$ , were added in amounts of 13-26 vol %. After the quenching, rolling and aging operations the diamond metal strips were subjected to





strength determinations. U.T.S grew after each processing stages. Tests were carried out on 45-75 mm diameter cutting disks produced by magnetic pulse stamping from the diamond metal sheets. Tests were performed at 4500-9000 rpm and feed rates of 20-500 mm/min. Corundum and silicon were used as work materials.

Important point to be highlighted in the rolling of diamond-sheet materials are that strength of tin-nickel-bronze can be increased by raising the Ni content of the binder, employing aging after quenching and cold working and decreasing the grain size of the diamond powder.

## **2.7 WEAR BEHAVIOUR OF DIAMOND DISPERSED METAL MATRIX COMPOSITE MATERIAL**

Grinding is a metal cutting process using tools with multiple cutting edges provided by randomly bonded abrasive grits of natural/synthetic origin which remove material at high speed, mostly under interrupted cut condition and improve or modify the shape, the dimension and the surface quality of the work piece. The grinding tool is made up of three distinct elements - (i) abrasive grits, diamond in the present case (ii) one or more filler (Ti or Ni) (iii) binder or bonding material (bronze). The main function of the last two elements, i.e. filler and the binder, is to anchor the abrasive grit in a carefully balanced fashion for optimal stock removal. Fig 2.10 depicts the components of a grinding wheel [9].

### **2.7.1 Material Removal Mechanism**

The material removal mechanism to be described does not deserve the name of theory. In spite of years of grinding practice, no comprehensive quantitative theory of grinding with diamond embedded in



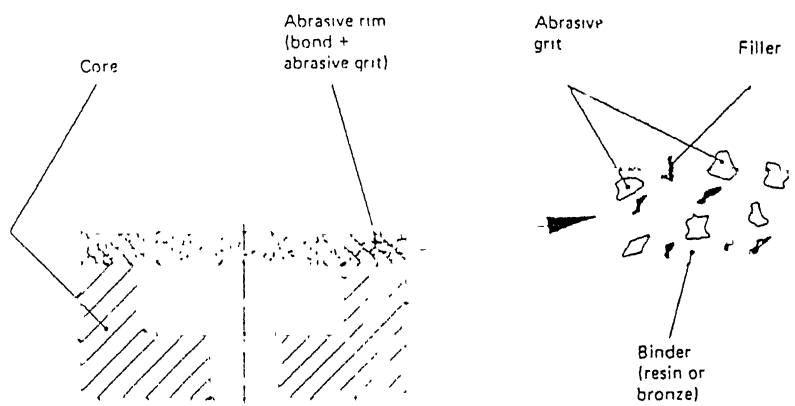
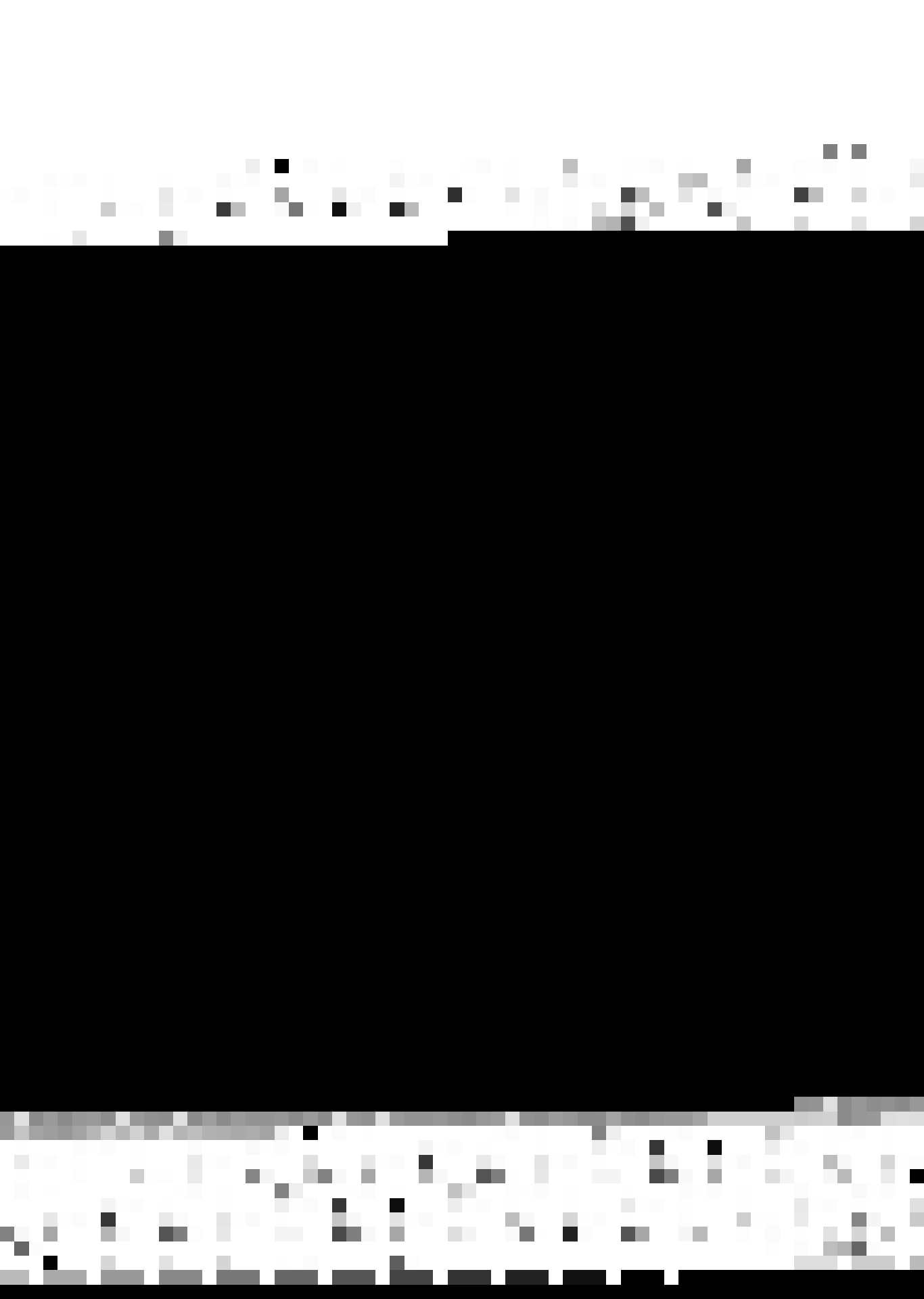


Fig 2.10 Components of grinding wheel



metal bond. In simplified approach, each grit is visualized as an approximate spherical body with a number of randomly oriented, sharp cutting edges. A given grit only contributes to stock removal if number of following conditions are fulfilled:

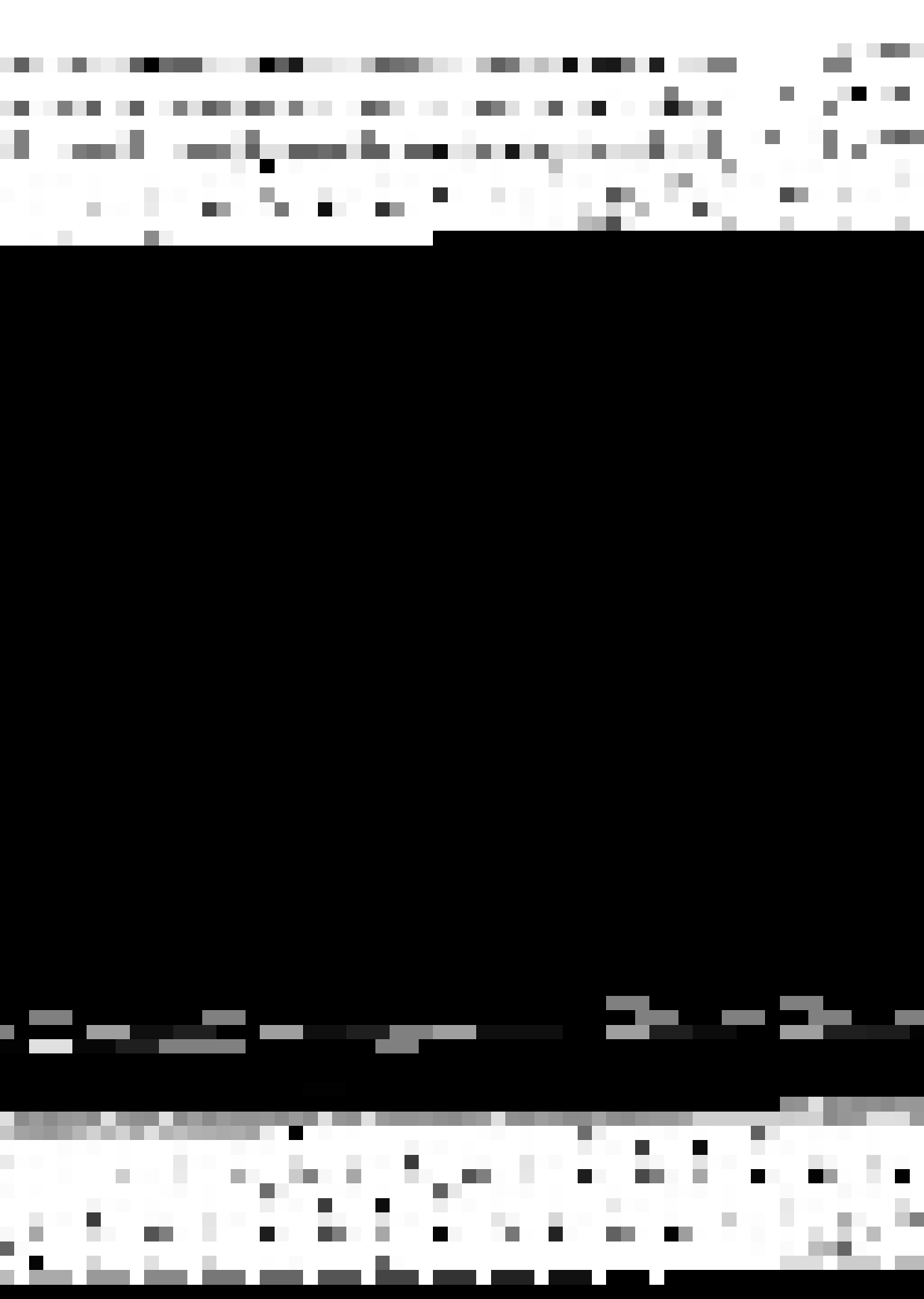
(a) Cutting edges must be sharp, and wear flats must not be present.

(b) The grit must be firmly held by the bonding material in order to withstand the forces generated by relative motions of grinding tool and work piece, while protruding partially above bond level.

(c) The grinding forces appearing on each individual grit must be high enough to allow the grit to penetrate into the work piece material and not only rub over it. Excessive forces, however lead to premature grit failure by wholesale pull out from the bond or by gross fracture and subsequent ejection from the holder.

Fig 2.11 depicts the forces generated during grinding by motions of work piece and tool. Crucial for the grit's fate or active lifetime are the tangential force component, which tends to pull out the grit as a whole block from the bond and tests the grit's retention in the bond, and the normal force component which puts to the test the grits friability. Friability is opposite to grit strength or grit resistance to impact.

The normal component is usually 2-3 times higher than the tangential component and, in this grinding mode, directly related to infeed. The force components applied to each grit are a function of the number of grit per unit surface of tool and the actual surface area of active interface. Fig 2.12 depicts the three cases of grinding forces. The interaction grit/bond/grinding parameters are to be understood with reference to three operating conditions differing in the magnitude of the



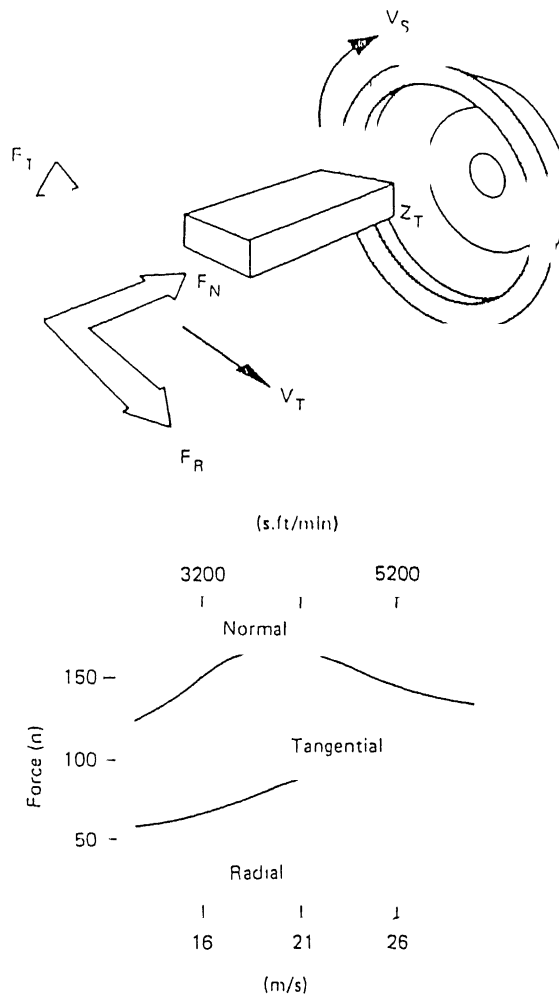


Fig 2.11 Forces generated during grinding by motions of workpiece and wheels

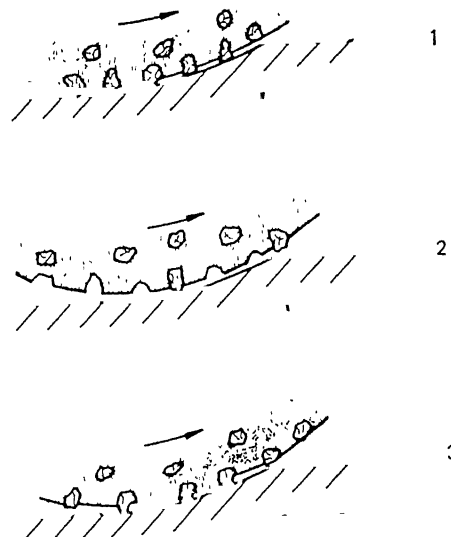
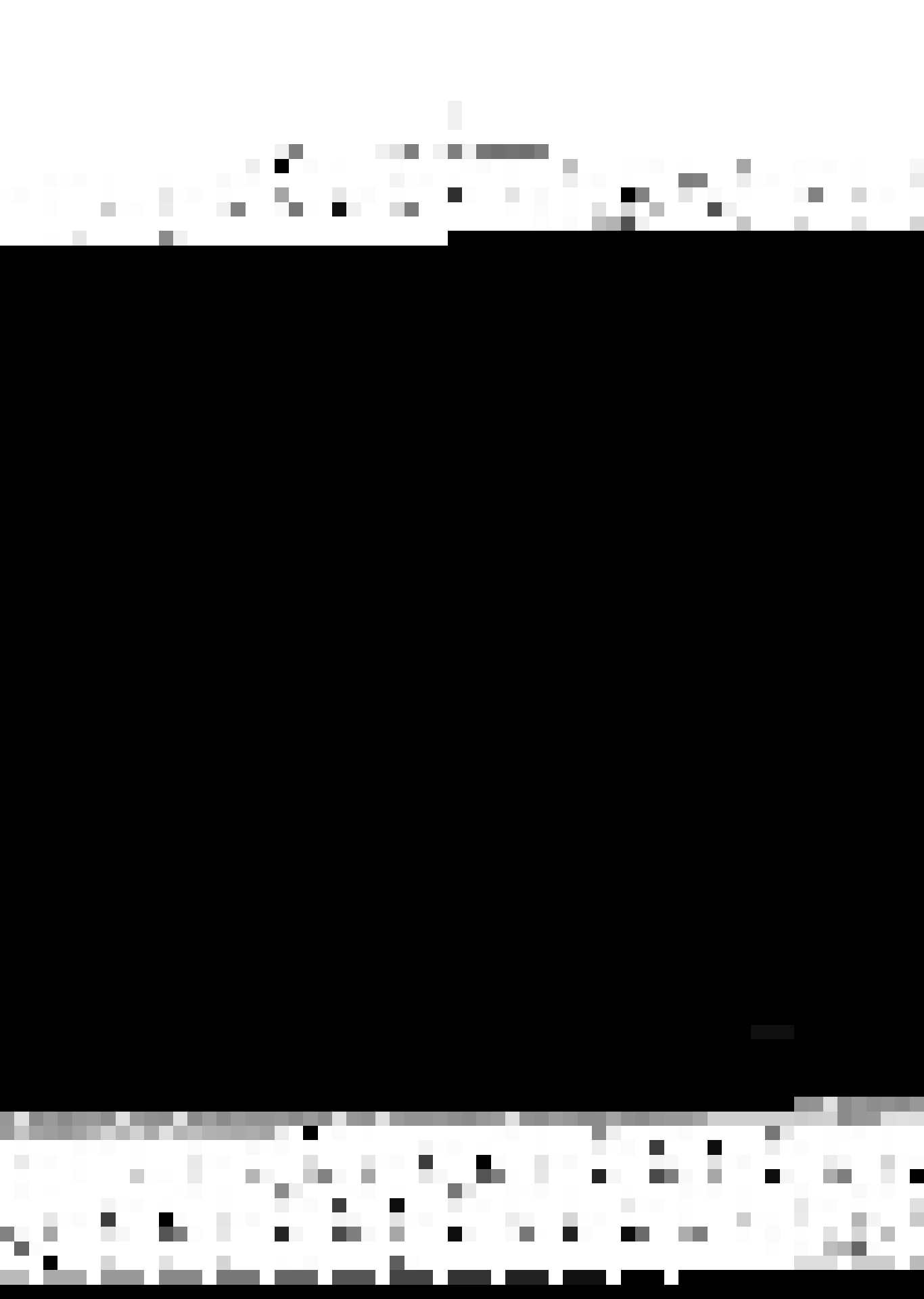


Fig 2.12 Three cases of grinding forces (1) insufficient (2) excessive





specific forces experienced by each individual grit on the work piece - tool interface [9].

(a) Insufficient grinding forces :

In this case, the cutting edges do not penetrate sufficiently into the work piece material. Instead of cutting, they rub against the work piece and lose their sharpness. The tool loses its freeness of cut and the progressive formation of wear flat reduces penetration into the work piece yet further.

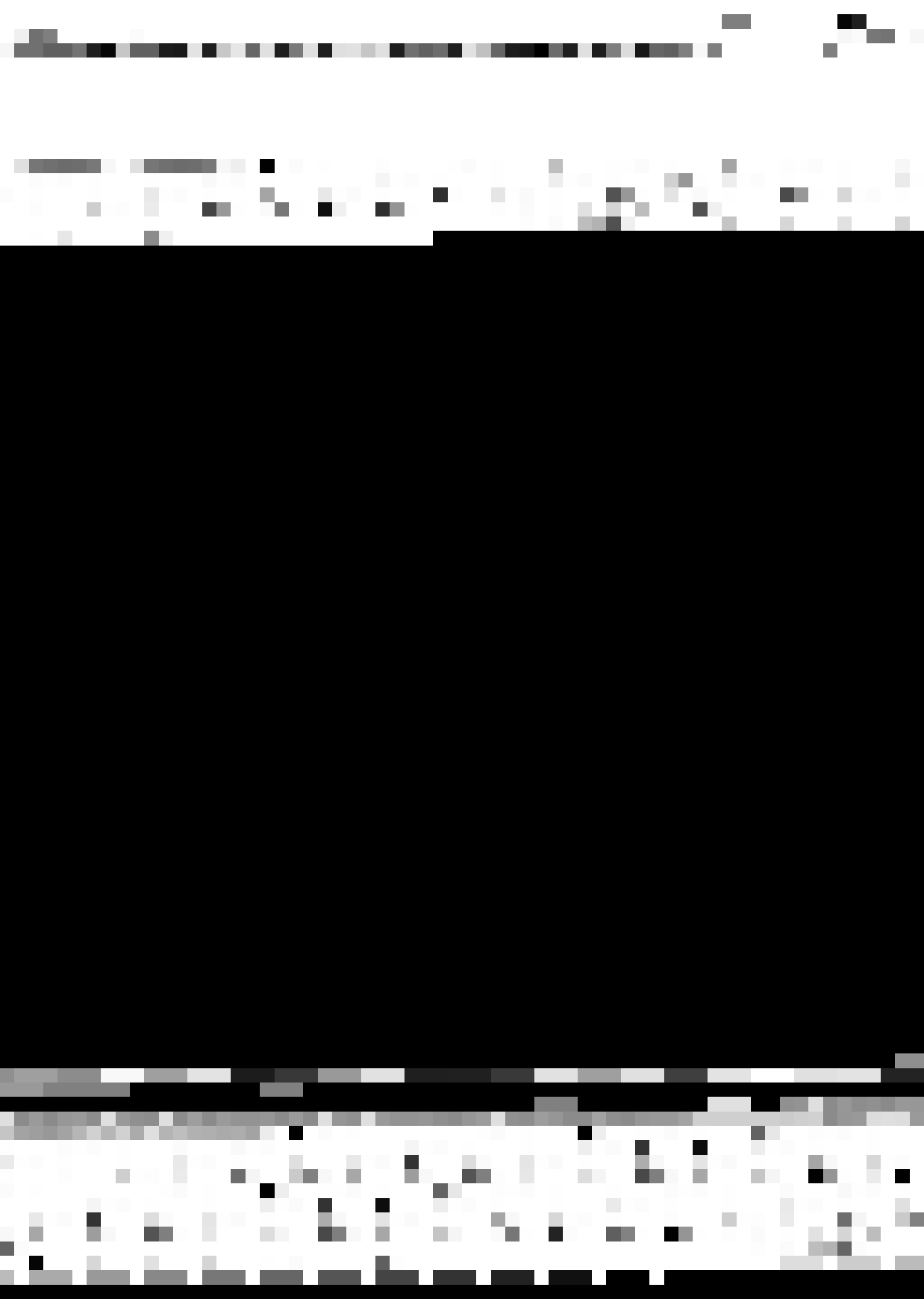
(b) Excessive grinding forces:

In this case, the combined effect of normal and tangential force components result in premature grit fragmentation and pull out. The individual grit hardly has a chance to contribute to stock removal. The grinding forces applied exceed the grit's resistance to pressure and the bond's capability with regard to grit retention.

(c) Ideal grinding forces:

In this case, the forces applied to each grit are adapted both to the bond's retention capability and the grit's friability. Wear flats do not develop, either because partial fragmentation generates new sharp cutting edges or because the entire remaining portion of the grit is dislodged from its socket .

The macroscopic wear recorded in a grinding operation arises from a number of causes which originate primarily either from grit attrition or from bond deterioration. Tool wear is due to the combined effect of bond wear and tool wear. Bond wear is due to chip friction against bond surface, friction of work piece against bond surface, thermal degradation of bond components from grinding heat. Grit wear is due to mechanical stresses on grit cutting edges (partial fracture) and on grid viewed as a unit, chemical attrition (reaction with work piece material or



coolant), thermal degradation of grit (oxidation and graphitization).

The important point to be noted in abrasive grinding is that the grinding process is dependent not only on abrasive and bond, but also on the nature of the material to be ground, and especially its resistance and response to mechanical stresses. Diamond grinding wheel can be seen not as a series of protruding tools with sharp cutting edges, but rather as a set of hammer heads, embedded in the bond, subjecting the material to be ground, a material of high brittleness and low toughness (eg. carbides), to short but intense compression peaks.

These compression waves destroy the cohesion of a heterogeneous material consisting of hard carbide grains, held together by metallic binder. The friable diamond grits, as long as they are well embedded in the bond, carry out their sledge hammer work for a considerable lapse of time. If the bond level recedes as a result of friction against the work piece, the protruding upper portion of the grit is, owing to the high friability of the grit chosen for this application, rapidly lost through partial fragmentation. The remaining portion of the grit, in its protective socket, continues its sledge hammer job undisturbed. This explains why the useful lifetime of diamond grits is higher.

Cracks and fracture of diamond particles can occur during cutting/grinding action. Although this could not be identified separately, but it could be assumed that it occurs as otherwise there would not have been any cutting action. It is postulated that formation and propagation of cracks is due to repeated loading in sliding contact. The origin of pits or cracks on the diamond surface can be formed by surface inclusions, indentation (pits) from the specific manufactured process, or indentation due to the ploughing action of wear particles. Cracks originating at the diamond surface propagate into the diamond in a direction inclined to the



surface. Propagation of cracks will eventually cause fracture of diamond particles. Localized fatigue may occur on a microscopic scale owing to repeated sliding contact of asperities on the surface of diamond. There are various hypothesis to explain above phenomenon. One hypothesis is the formation of sub surface cracks. The maximum hertzian contact shear stress is increased by internal inclusions or other defects in the diamond particles and induces sub surface cracking. This type of fracture may cause the delamination of diamond particle are subjected to impact loading with the generation of shock waves travelling through internal inclusion or surface pits of the diamond particles. This theory is confirmed by Wright and Wapler [29].

Direct evidence of diamond graphitization during cutting could not be identified. Nevertheless, if graphitization of the diamond occurs it will contribute to the wear of the diamond. This may explain the process of grain dulling. Liao and Luo [30], studied the SEM of the diamond saw blade used for circular sawing of granite. It can be presumed that the wear behaviour of diamond will be closely associated with the present work. They classified the worn diamond particles into the following and this can also be seen from the Fig 2.13.

(a) Whole diamond/good diamond:

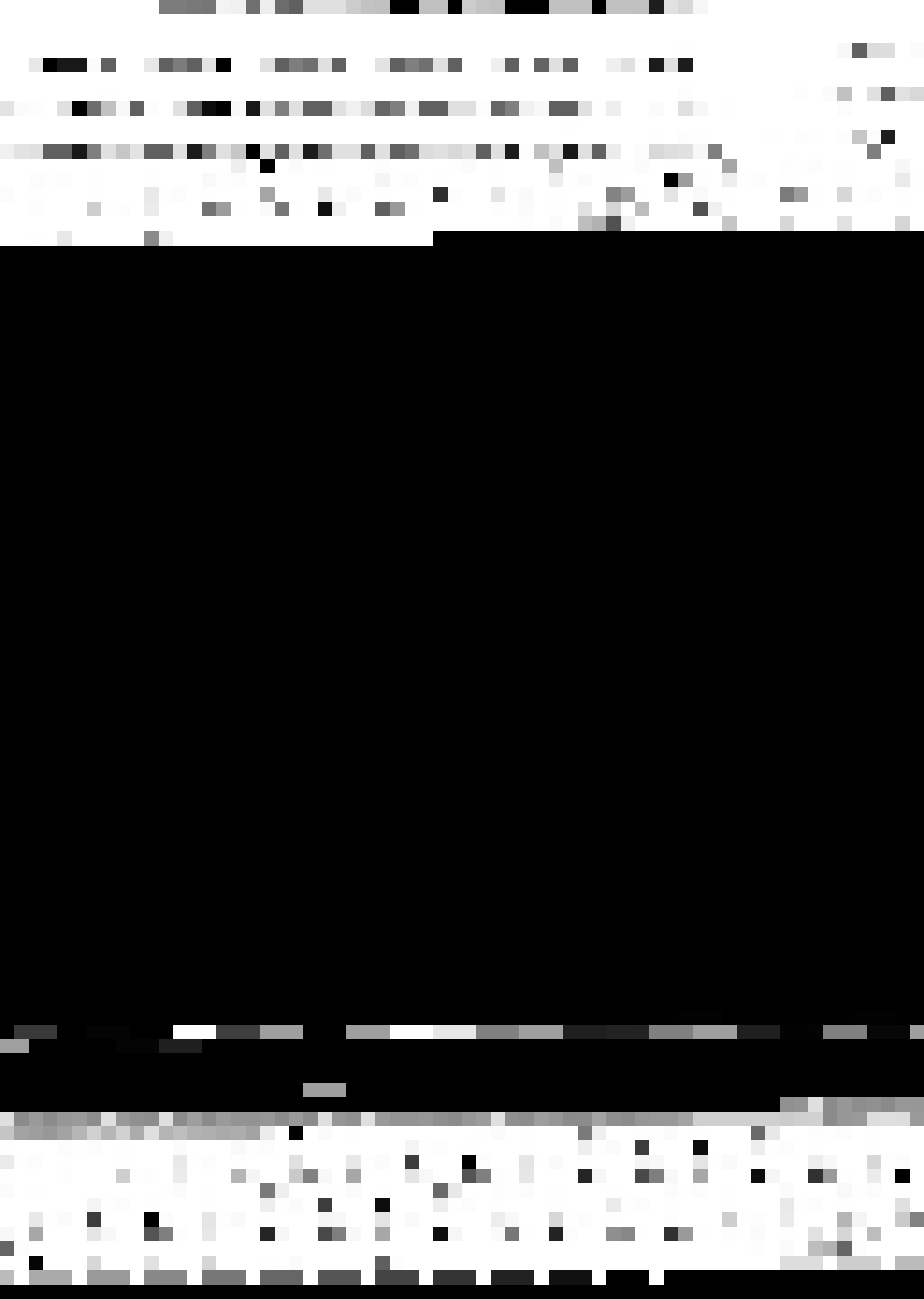
This is the particle protruding above the surface of the matrix which performs the cutting work while retaining its crystal shape and exhibits no significant surface damage.

(b) Polished(flattened) diamond:

These particles display a worn area of smooth or flat faces. This wear is most probably caused by mechanical attrition.

(c) Micro-fractured diamond:

The particles present micro cracks, crushed particles, or



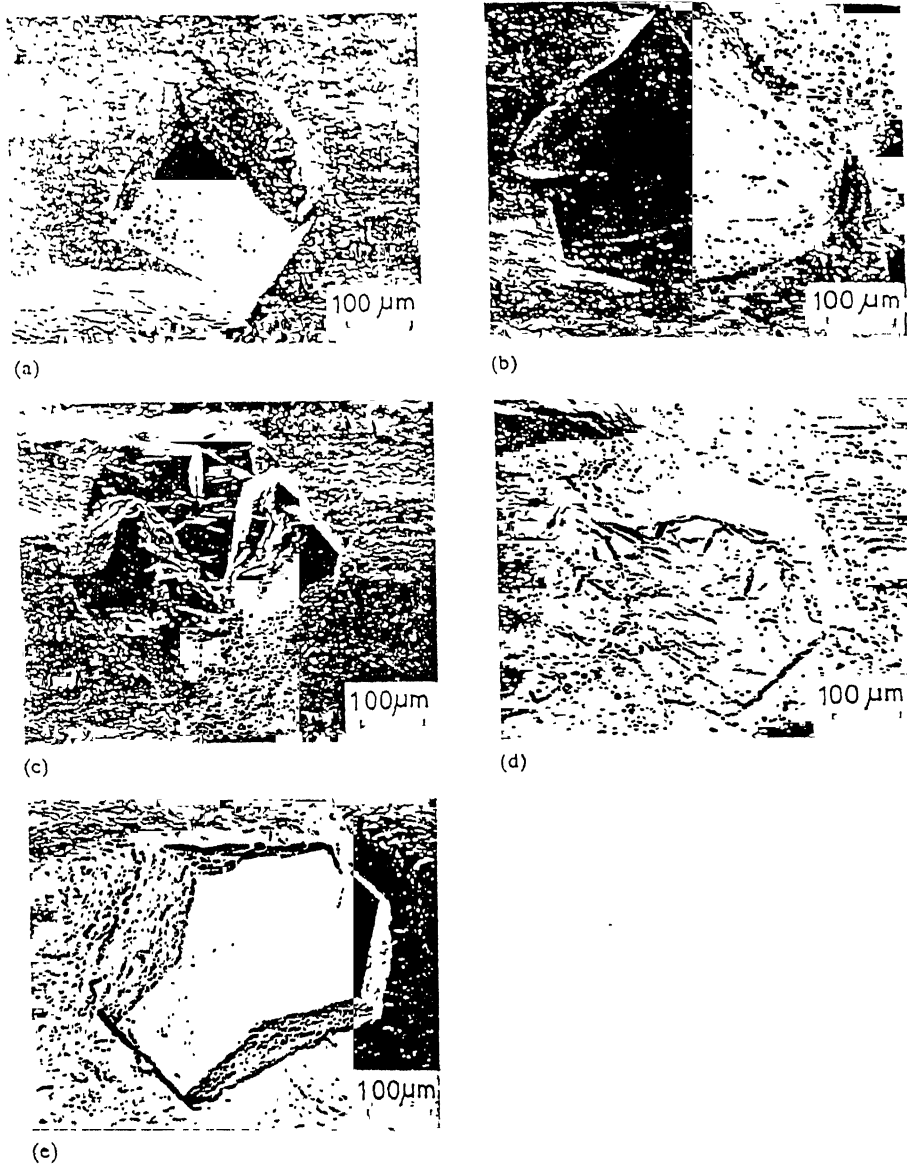


Fig 2.13 Classification of worn diamond particles (a) good (b) polished (c) micro-fractured (d) macro-fractured (e) pulled-out





fragments on the crystal surface. It may be result of repeated impact or surface fatigue with work piece materials. This type of crystal is considered to be of great aid to free cutting.

(d) Macro-fractured diamond:

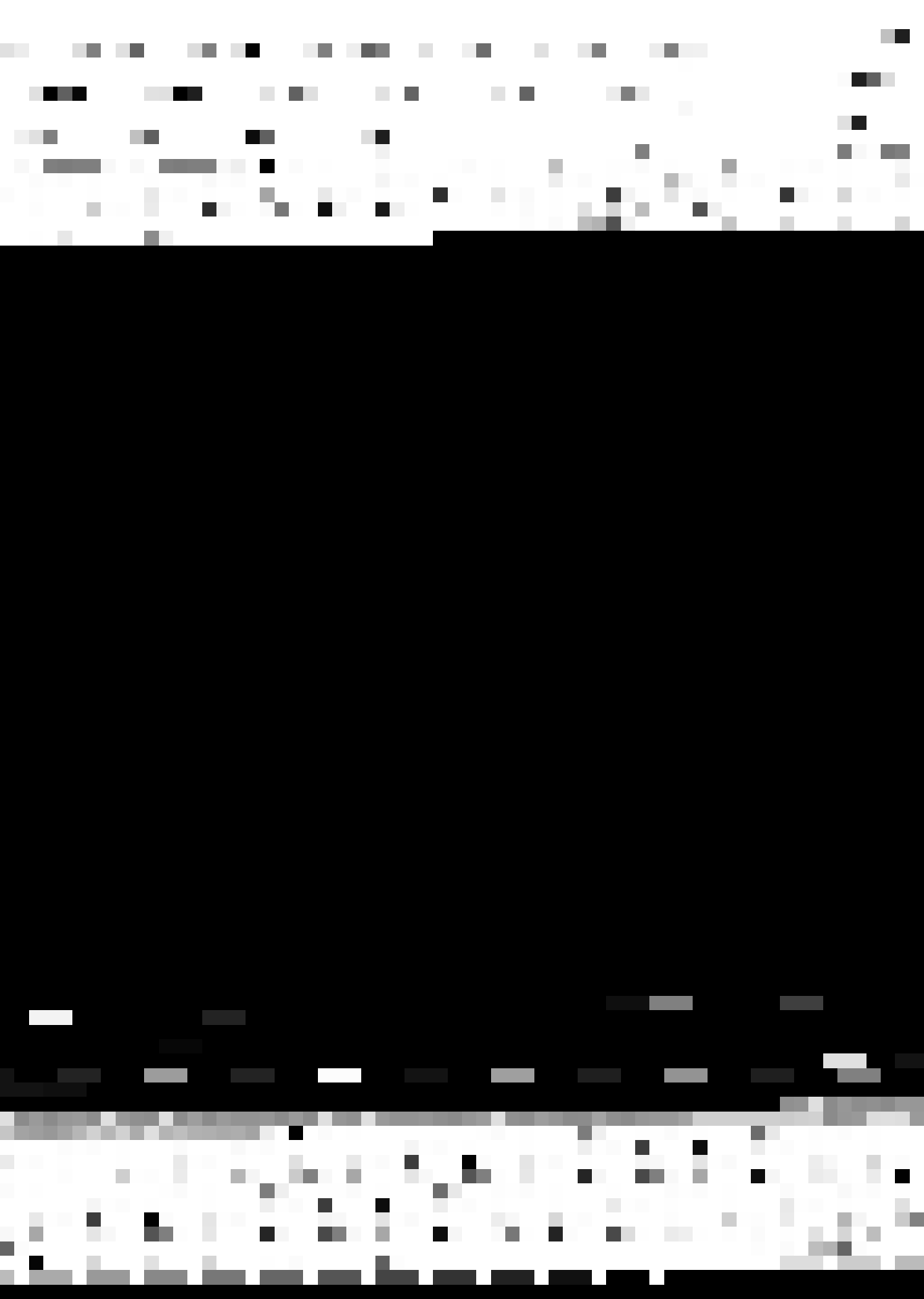
This is probably further damage of the previous classification of wear. The cutting edges of such particles protrude above the surface of the matrix a little and affect significantly the cutting ability. In an extreme case, wheel will lose its cutting capacity.

(e) Pulled out diamond:

The appearance of the diamond pulled or plucked out of the bond is hole on the worn surface. If the diamond is pulled out of the bond before completing its effective working life, the cutting tool will wear very fast.

In a nut shell it could be said that : synthetic diamond crystal from the abrasive layer of cutting tool preserve the characteristic given by four wear mechanisms:

- (i) adhesive wear is accompanied by forming of built-up edge.
- (ii) abrasive wear is rarely observed due to extreme hardness of diamonds.
- (iii) corrosive wear, i.e. the tribochemical interaction of diamond with the surrounding medium and with the work piece material and is emphasized by blunting of the cutting edges. Cohesive wear is present especially at high peripheral speeds.
- (iv) surface fatigue wear due to result of the extra hard material.

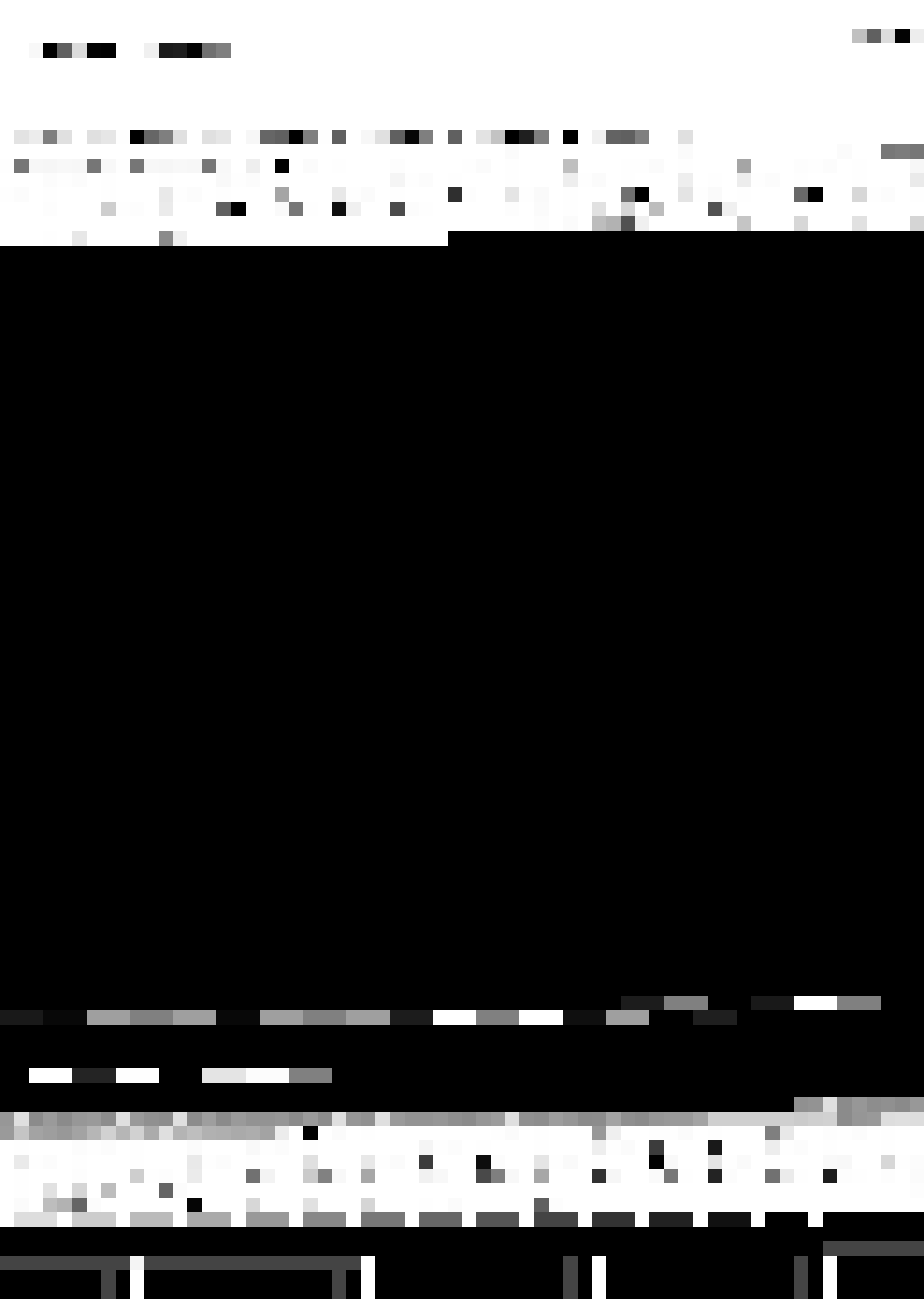


## 2.8 AIM OF THE PRESENT STUDY

As discussed earlier sintered diamond composites are very important tools for removal of materials such as grinding, sawing and other machining processes. These tools are particularly effective when they are used to process hard and brittle materials such as ceramics, stone, concrete, glass. The effective use of diamond abrasives in metal bond tools depends to a large extent on the materials that are used to hold and support the diamond particles while they do their work. The strength of the composite materials is markedly affected by the filler material (eg. Ni and Ti). Rolling of diamond-metal composite material is a modern and reliable method for the manufacture of diamond tools with a large working surface, small thickness with uniform density across the entire tool surface. The processing steps for the manufacture of metal-diamond composite tool are very important. Keeping this in view, present work was undertaken with the following aims:

(a) To study the feasibility of rolling diamond-bronze composite material, optimization of processing steps, and effect of Ni additions, while rolling above composite material.

(b) To study the effect of Ti additions to diamond-bronze composite material.



## CHAPTER 3

### EXPERIMENTAL SET-UP AND PROCEDURE

#### 3.1 RAW MATERIALS

Raw materials used in this present investigation were:

- (a) Diamond powder: A total of 100 CT was obtained from MEGA DIAMOND, U.S.A.
- (b) Bronze powder: Composition of Bronze powder was 90% Cu and 10% Sn.
- (c) Nickel powder: INCO type 123 Ni powder was used for present experiments.
- (d) Titanium powder: These were obtained by filing round Ti bars obtained from MIDHANI, HYDERABAD. Purity levels of the bars were 99.8%.

The above powders were characterised for particle size distribution by Coulter counter model  $Z_B$  and B. Particle size distribution by the above instrument could not be carried out for Ti powder as the powders were very coarse. The above method is based on measuring the change in electrical resistance when particles were suspended in electrical conducting liquid, pass one by one through an aperture in between the electrodes. The change in resistance produces voltage flux which is proportional to particle volume. Particle size was determined by this method is defined by the cube root of particle volume. NaCl was the electrolytic medium. The particle size distribution is presented in the form of bar chart in Fig (4.1). All the powders were observed under JEOL JSM 840 A Scanning Electron Microscope (SEM) in order to observe their



morphology. Relevant microstructures are presented in Chapter 4. Fig 3.1 shows the various steps involved in the processing of diamond dispersed metal matrix composite.

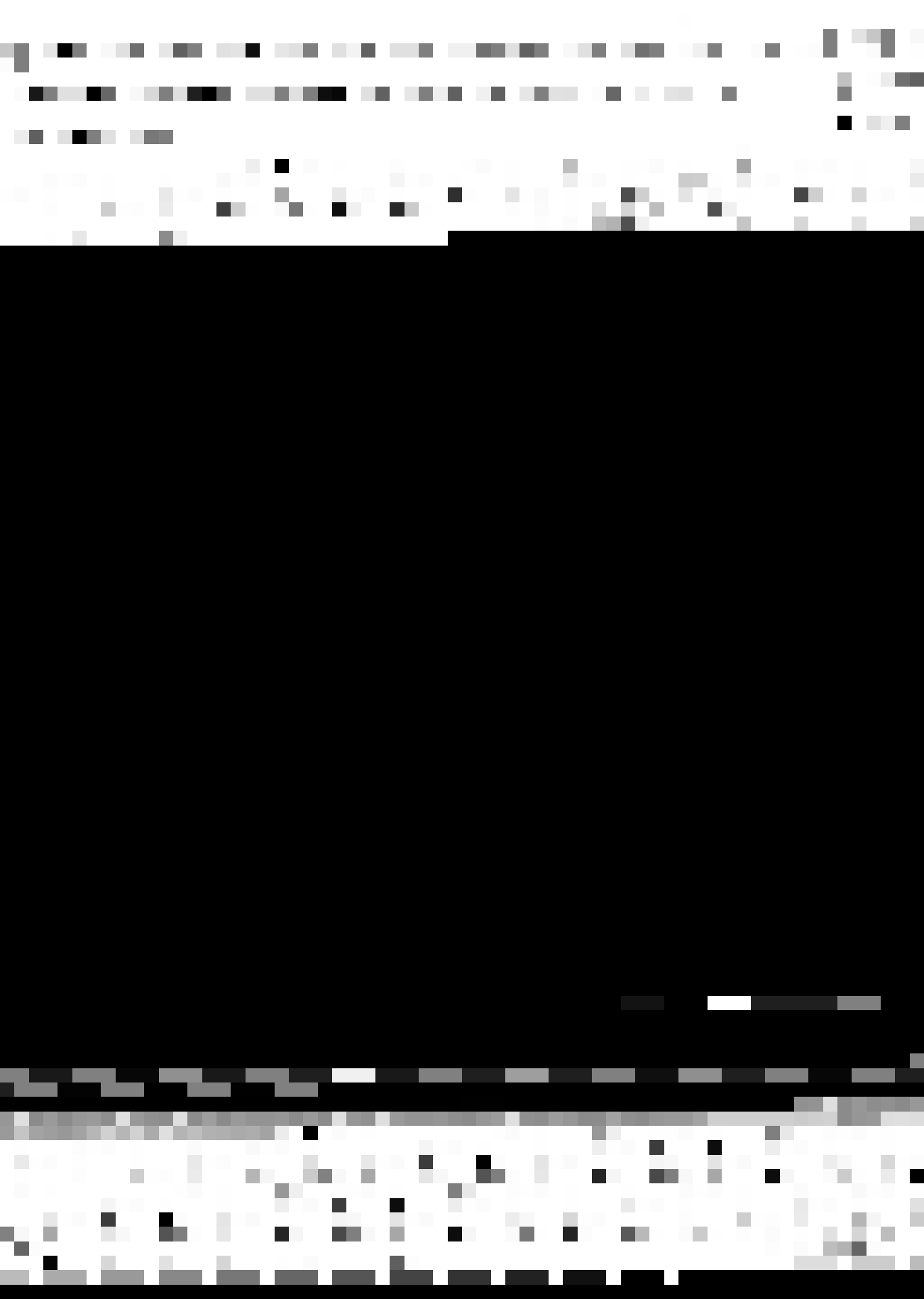
### 3.2 POWDER MIXING

Diamond and bronze powders in the ratio of 2:1 (wt% basis) were mechanically mixed using a motor and pestle for 60 min. When Ni and Ti powders were subsequently added, the mixing time was increased to 90 min. This step is very important as the uniformity of the final product depends on the efficiency of mixing. Improper mixing or mixing for a less time might lead to segregation in the final product. Ni powder (4 wt%) were also added to the original Diamond-Bronze (DB) mixture. 5 wt% Ti, 10 wt% Ti and 15 wt% Ti powders were added to original diamond-bronze mixture to get samples of varying Ti concentration. To get diamond-bronze-nickel-titanium sample, Ni (4 wt%) and Ti (10 wt%) were added to original diamond-bronze mixture and the mixing was carried out for 90 min.

### 3.3 COLD COMPACTION AND SINTERING

Powder mixture corresponding to the composition studies were compacted into cylindrical pellets in a steel die using hydraulic press at a pressure of  $350 \text{ Kg cm}^{-2}$ . The compacts were of 3.68 cm dia and 5 mm in height. The die wall was lubricated with Zinc stearate prior to powder filling. Methyl cellulose was used as binder. Height and diameter of the pellets were measured using a vernier calliper and from these, the volume of the pellets were determined. Weight of the pellets were determined by





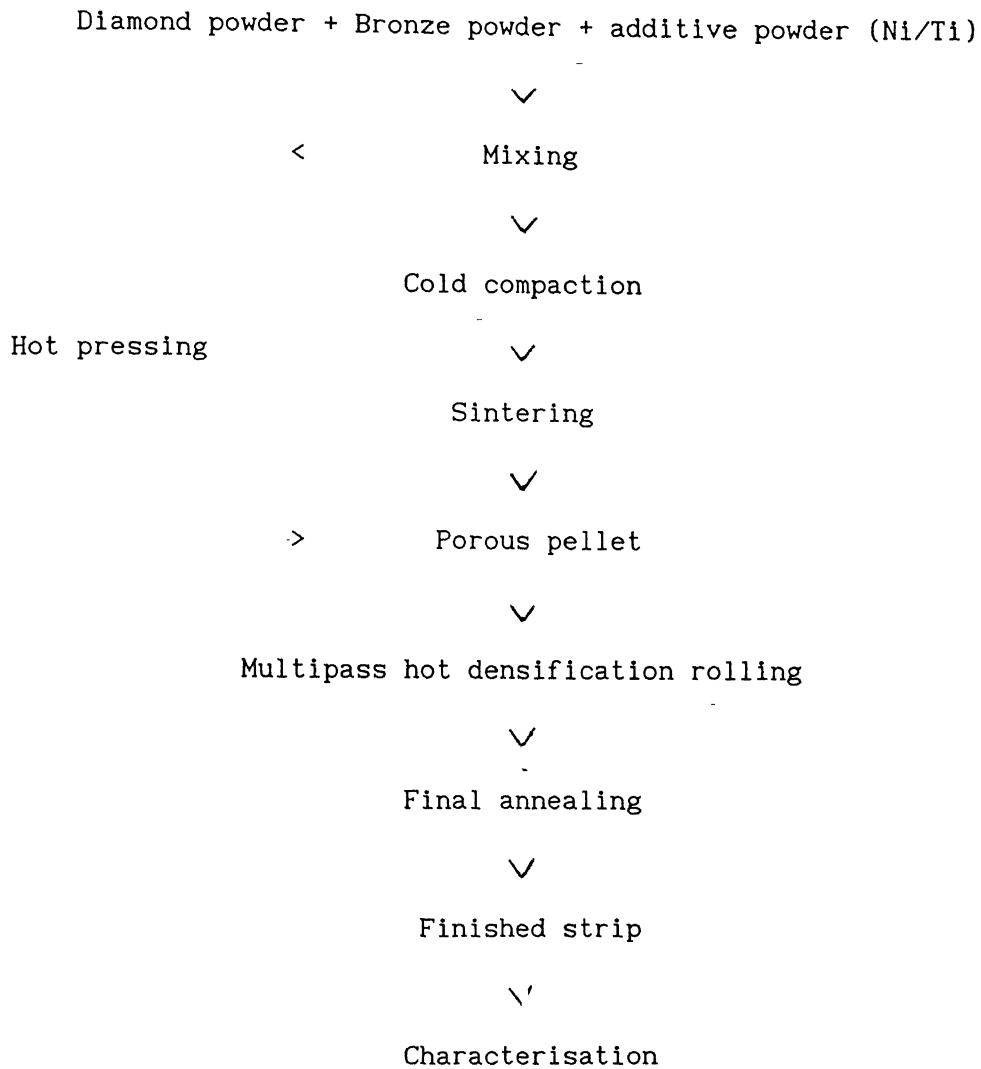
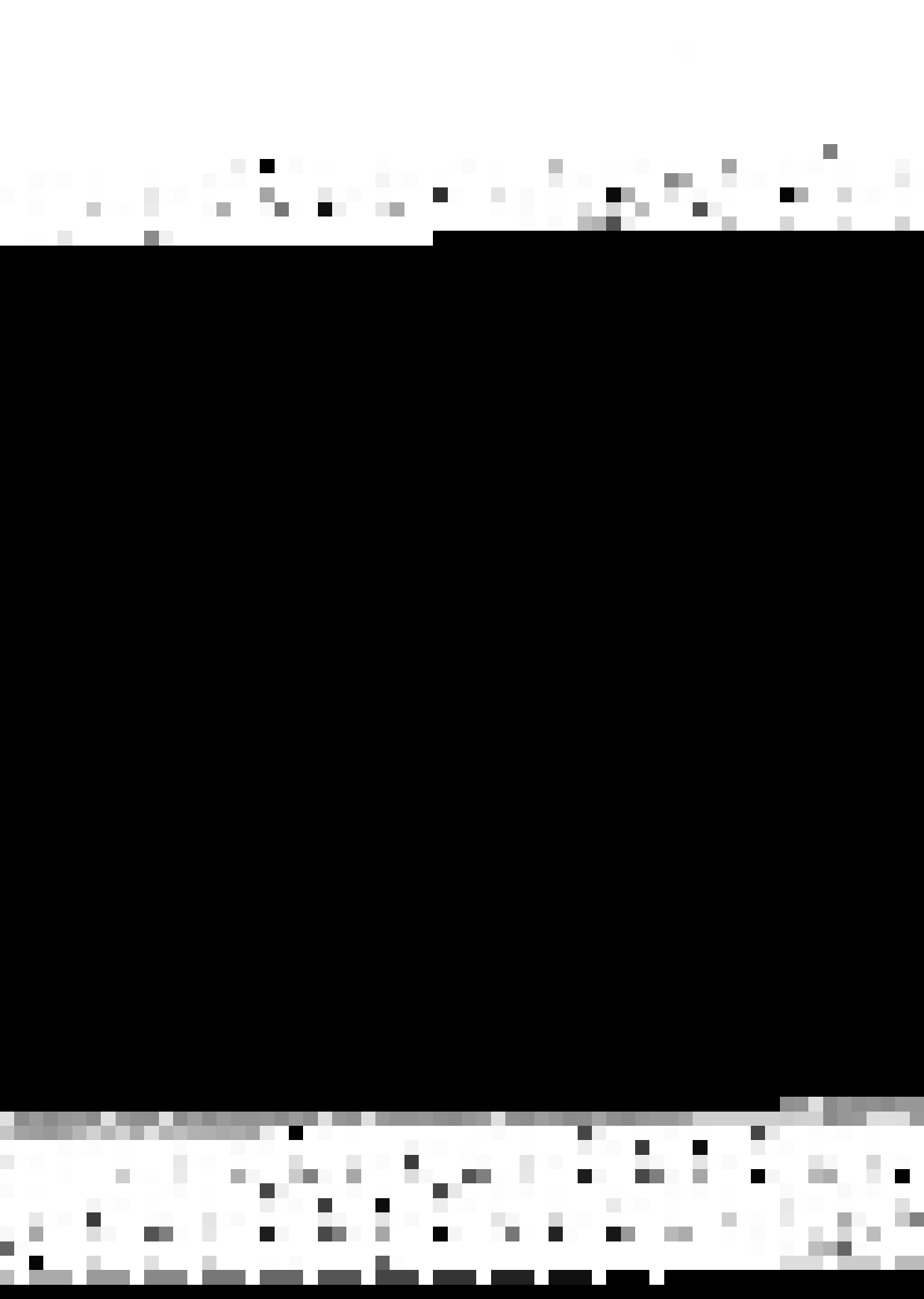


Fig 3.1 Various steps involved in the processing of diamond dispersed metal matrix composite.



electronic balance. From the weight and volume, their densities were calculated. Only diamond-bronze (2:1) mixtures were cold compacted. Green compacts were found to have 55.6% of the theoretical density. The aim of the compacted was to (a) to consolidate the powder into desired shape (b) to impart desired level of porosity and (c) to impart adequate strength for subsequent handling.

The green pellets were charged slowly into a horizontal tube Inconel furnace, having SiC heating elements. The furnace was closed from one end and had the provision for maintaining a protective atmosphere. The temperature was fixed at  $800^{\circ}\text{C}$  and an  $\text{H}_2$  atmosphere was maintained throughout the experiment. The green pellets were heated for 2 hr in  $\text{H}_2$  atmosphere. Cooling was done for 1 hr in  $\text{H}_2$  atmosphere. Compacting and sintering route were not carried out for the mixtures containing Ni and Ti.

### 3.4 HOT PRESSING

Hot pressing was used because of difficulty associated with conventional compaction and sintering to obtain high density parts. Here both pressure and temperature are applied simultaneously. Advantage in hot pressing is that even at very low pressure in conjunction with low temperature, higher densification can be obtained in shorter time. No protective atmosphere is required, due to intimate contact of powders mass and die/punches. In a hot press heating is done by induction coil. Pt/Pt-Rh thermocouple was used to measure the temperature. Height of the die was 5 cm and the pressure was applied by hydraulic rams. Graphite punch and dies were used. Prior to filling of powders in the die, the punch and die surface were cleaned with acetone to remove dirt particles. Die of half inch and one inch were used to make the required samples.

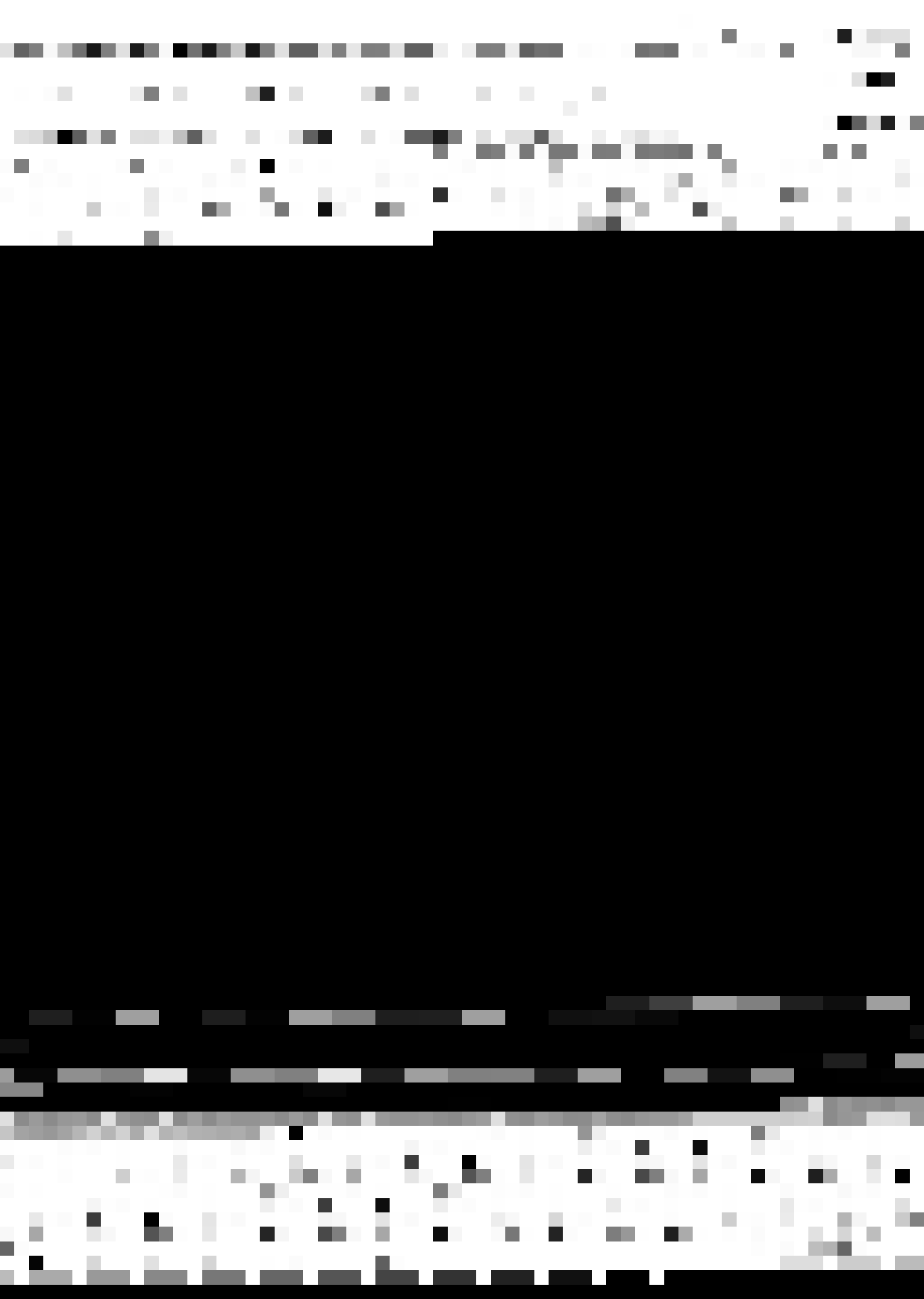


Temperature was maintained at  $820^{\circ}\text{C}$  for diamond-bronze mixtures and it was slightly increased to  $840^{\circ}\text{C}$  for diamond-bronze-nickel and diamond-bronze-titanium mixtures. Pressure was slowly increased with the increase in temperature and as the temperature crosses  $800^{\circ}\text{C}$ , pressure of 0.4 tons/sq. inch was applied. This is the maximum possible pressure which could be applied without causing damage to the punch and dies. Holding time at the maximum pressure has the important influence in the density of the compact. Thus the holding time was optimised for D-B mixtures, D-B (Ni) and D-B (Ti) mixtures. After various trial and error the holding time to achieve best results for D-B mixture was found to be 45 min. 60 min for D-B(Ni) mixture was found optimum. For D-B (Ti) mixtures, hot pressing was carried out for 60 min and these were further sintered for 1 hr in a tube furnace in Ar atmosphere. For hot pressing D-B (Ti) mixtures, special precautions were taken to avoid oxidation of Titanium. For these small round steel foils were cut and was placed just beneath the top punch and also on top of bottom punch. All the samples during hot pressing was cooled inside the graphite die.

Hot pressing was done for, D-B (2:1), D-B (4 wt% Ni), D-B (5 wt% Ti), D-B (10 wt% Ti), D-B (15 wt% Ti) and D-B (4 wt% Ni + 10 wt% Ti) mixtures.

### 3.5 HOT ROLLING

Hot rolling was carried out for hot pressed D-B and D-B (4 wt% Ni) samples to densify the material and to remove porosity. Hot rolling was carried out in subsequent passes. Samples were packed in a Cu foil and transferred into a Inconel tube furnace with SiC heating elements. Packing was done to prevent oxidation. Small hole was drilled near one edge of the



packing material through which a thin nichrome wire was tied. This was done for easier handling during hot rolling. Drilling a hole on the composite sample was not possible. Heating was done at  $700^{\circ}\text{C}$  for 2 hr in  $\text{H}_2$  atmosphere. Hot rolling was done on a two high mill having 135 mm dia rolls rotating at a speed of 55 r.p.m. The reheating furnace was interlinked with the rolling mill in such a manner that the sample remained in  $\text{H}_2$  atmosphere up to the nip of the rolls. Thickness reduction was done by pulling the sample by the wire and forcing between the two rolls. The hot rolled strip was cooled in a bed of graphite chips, immediately after hot rolling to prevent internal oxidation caused by porosity. After each pass, the packing material was removed and the cracked edges were sheared off. Samples were prepared after each rolling pass and was kept for characterisation.

### 3.6 CHARACTERIZATION METHODS

#### 3.6.1. Density And Porosity Measurements

The density of Hot pressed as well as rolled samples were measured by displacement method. The samples were first dried in an oven for 1 hr at  $60^{\circ}\text{C}$ . They were then weighed in air ( $W_A$ ). These were then xylene impregnated by putting the sintered compacts in xylene in a vacuum desicator under a constant suction for 30 min. The impregnated samples were first weighed in air ( $W_B$ ) and then in water ( $W_C$ ). The sintered density expressed as percentage of the theoretical density was given Arthur formula:





$$\text{Sintered density} = \frac{W_A}{W_B - W_C} \text{ g/cc} \quad (3.1)$$

$$\% \text{ Porosity} = \frac{1 - \frac{\text{sintered density}}{\text{theoretical density}}}{1} \times 100 \quad (3.2)$$

Density was measured for all the hot pressed specimens of different compositions. Density was also measured for the rolled samples at different deformation stages.

### 3.6.2 Scanning Electron Microscopy

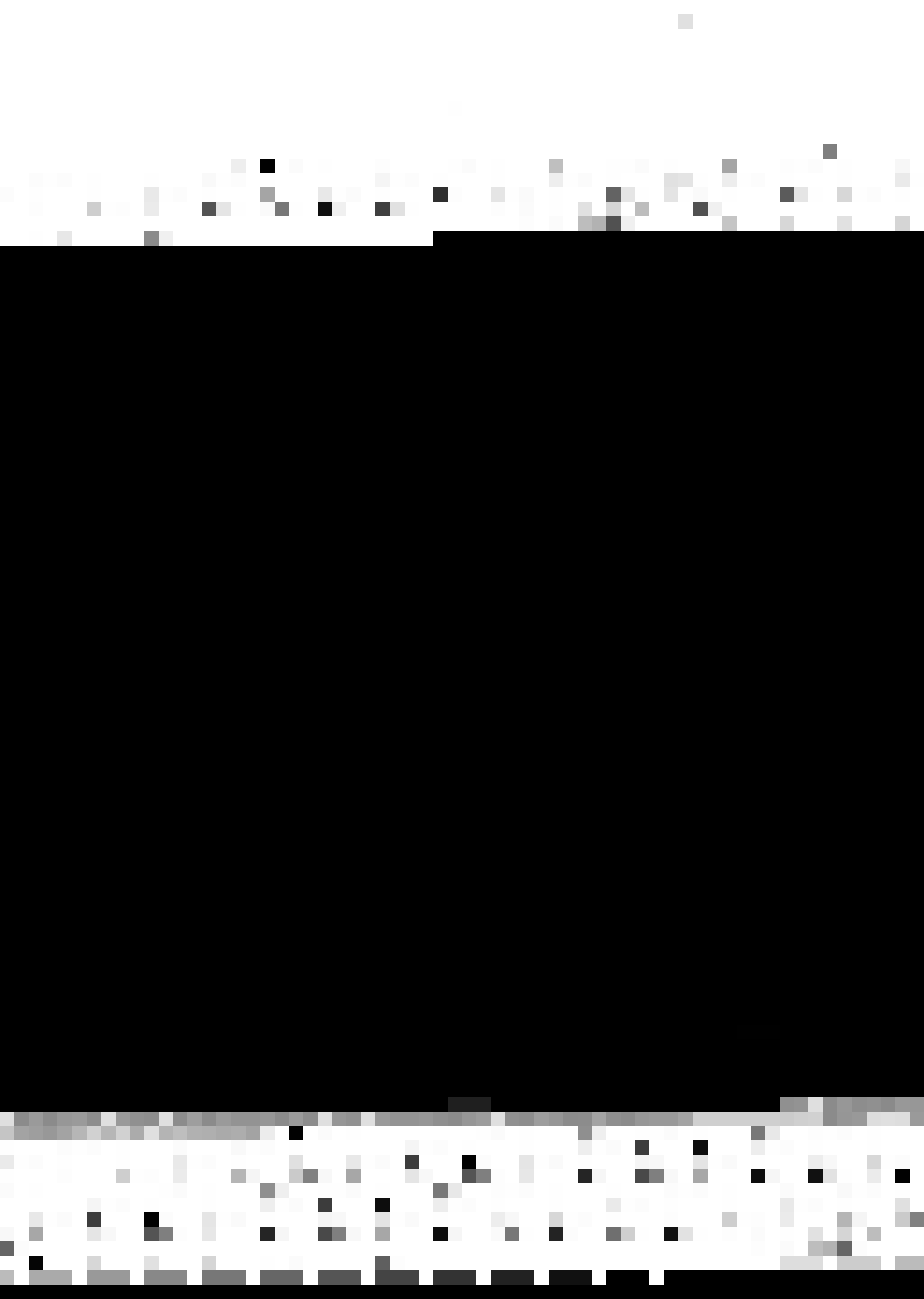
JEOL JSM 840A, Scanning electron microscope was used to observe powder morphology, microstructure of hot pressed and hot rolled specimens. For viewing the deformed structure, samples were mounted with the help of cold setting powder and resin. The sample preparation consisted of polishing first on various grades of emery papers and then fine wheel polishing with diamond paste and kerosene. The rolling direction along the thickness of the rolled samples was kept as the direction of observation.  $\text{FeCl}_3$  was the etching reagent and the etching time was 15 sec.

### 3.6.3 Microhardness Testing

Microhardness of the rolled D-B material and that of rolled D-B(4 wt% Ni) was measured by Leitz Miniload Microhardness Tester. Various readings were taken to note the variation of hardness from one region to another. Microhardness of the matrix for D-B(10 wt% Ti) composite was also measured. The same sample prepared for SEM was used in the determination of microhardness.

### 3.6.4 Wear Resistance

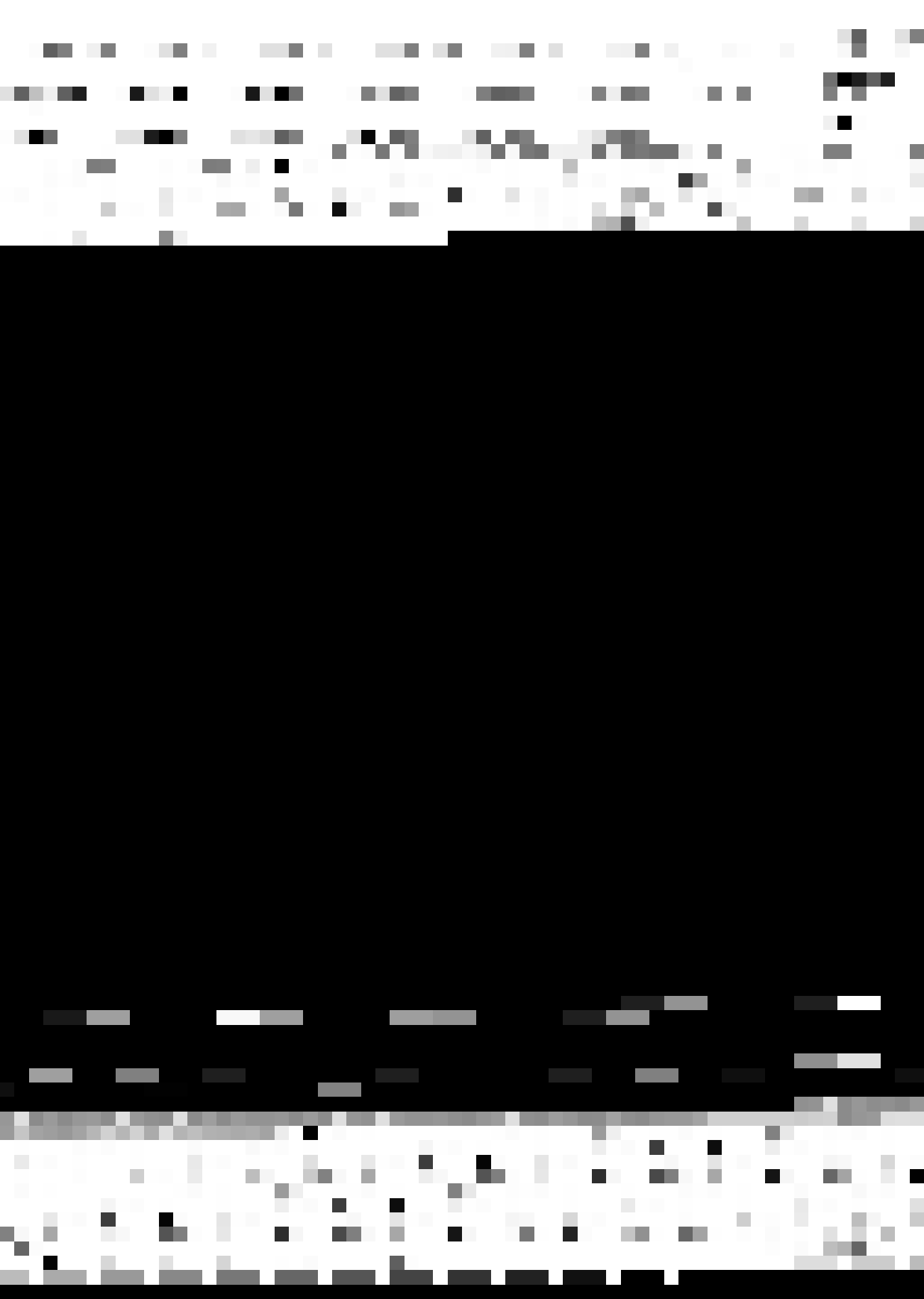
Tool life testing have been compiled by carrying out simple lathe



turning tests in continuous cutting, using tools with a standard geometry and measuring the width of the flank wear land. Flank wear was considered as a criteria to get some idea about the wear resistance of diamond-metal composite material. Flank wear was measured for both hot pressed and rolled samples. Samples were brazed to a mild steel plate and it was fixed to a tool holder of lathe machine. Ruptam (Cu-Ag) was used as a brazing material. Brazing of the tool to the mild steel was very difficult due to the porosity of the samples. Negative rake angle of  $2^\circ$  was given to the diamond samples while carrying out the cutting test. Alumina tube of 4 cm diameter was chosen as the work piece material. Samples were tested against work piece material, brazing material was removed, and shadow graph of the samples were taken on a tracing paper, after interval of 15 and 30 min. This was compared with the shadow graph of the original sample. The difference in the readings divided by the magnification gives the width of the flank wear land. Depth of cut by each specimen after 30 min was also measured with the help of a Travelling Microscope. In the above investigation the velocity of Alumina tube was 1000 rpm and the feed/rev was 0.053 mm/rev.

### 3.6.5 X-RAY Analysis

X-ray diffraction patterns for hot pressed D-B compacts, D-B(4 wt% Ni) compacts, D-B(10 wt% Ti) compacts were taken. The aim was to verify the formation of graphite, which is a transformation product of diamond at high temperature. X-ray study of D-B (10 wt% Ti) was carried out to trace the formation of TiC. X-ray diffraction was carried out with  $\text{Cu-K}_\alpha$  radiation. The phases were identified by matching the obtained data with the Standard ASTM data.



## CHAPTER 4

### RESULTS AND DISCUSSION

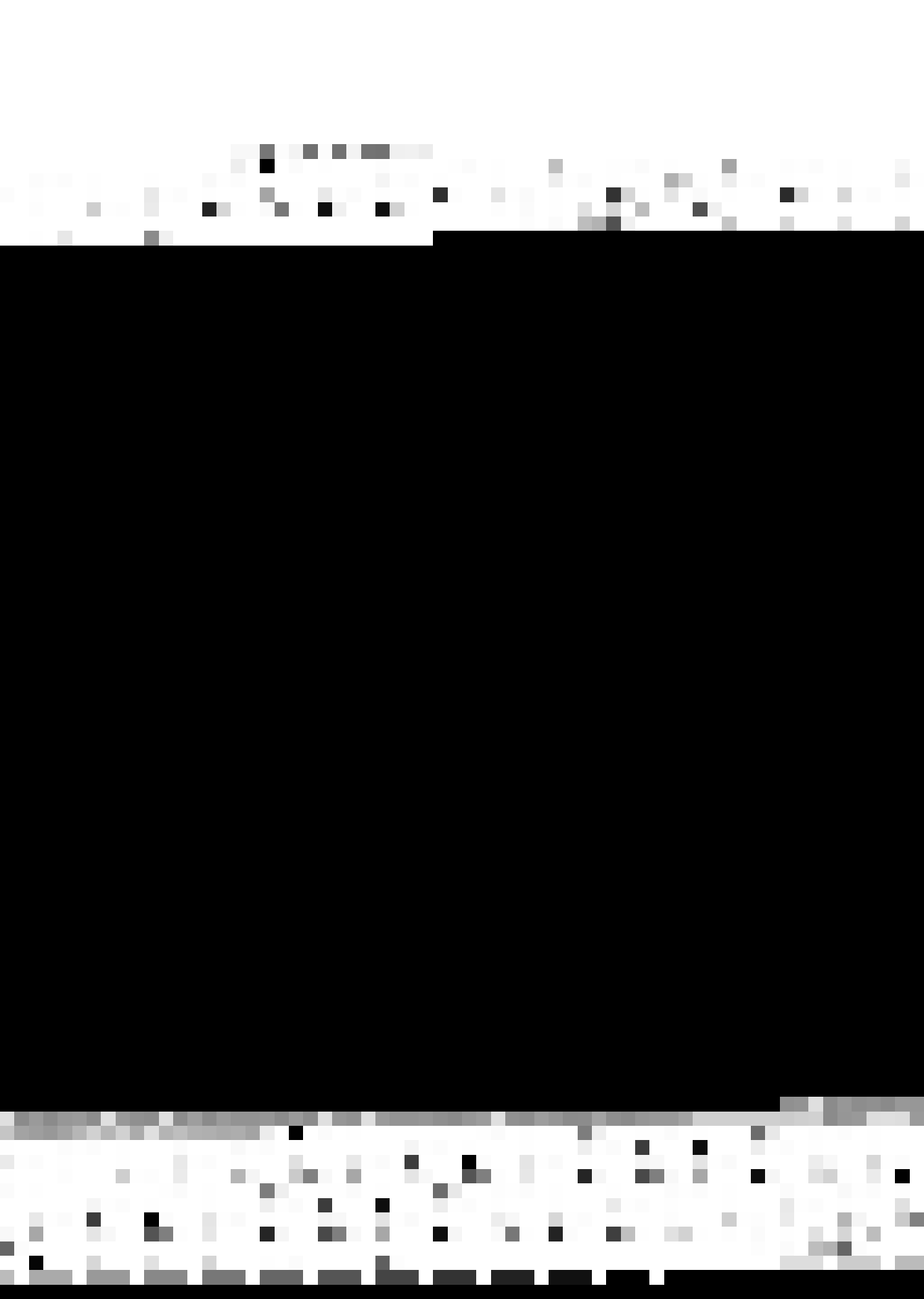
In the present work, processing and properties of diamond dispersed metal matrix composites were investigated. Diamond dispersed metal matrix composites which were studied comprises of (a) Diamond-Bronze composite material and Diamond-Bronze composite with 4 wt% Ni (b) Hot pressed Diamond-Bronze-Ti-Ni composite material of various compositions. These are discussed in the subsequent sections.

#### 4.1 DIAMOND-BRONZE AND DIAMOND-BRONZE-4 wt% Ni COMPOSITE MATERIAL

These composite materials are processed through either Cold compacting-Sintering-Hot rolling route or Hot pressing-Hot rolling route.

##### 4.1.1 Processing and Densification Behaviour

The result of Cold compacting-Sintering-Hot rolling of Diamond-Bronze (D-B) composite route is summarised in Table 4.1. Density after cold compaction is 55.6 % of the theoretical density and it increased to 60.2 % of the theoretical density after sintering at 800°C for 2 hr in H<sub>2</sub> atmosphere. Porosity of the final sintered sample is found to be 39.80%. Sintering in H<sub>2</sub> atmosphere is carried out to prevent oxidation of the samples. These samples are fragile and lacked adequate strength. When these pellets are subjected to thickness reduction by hot rolling, it crumbled, unable to withstand the rolling load. It can be inferred from the above observation that adequate bond strength is critical for rolling of D-B composite material. Therefore, the above mentioned route is not



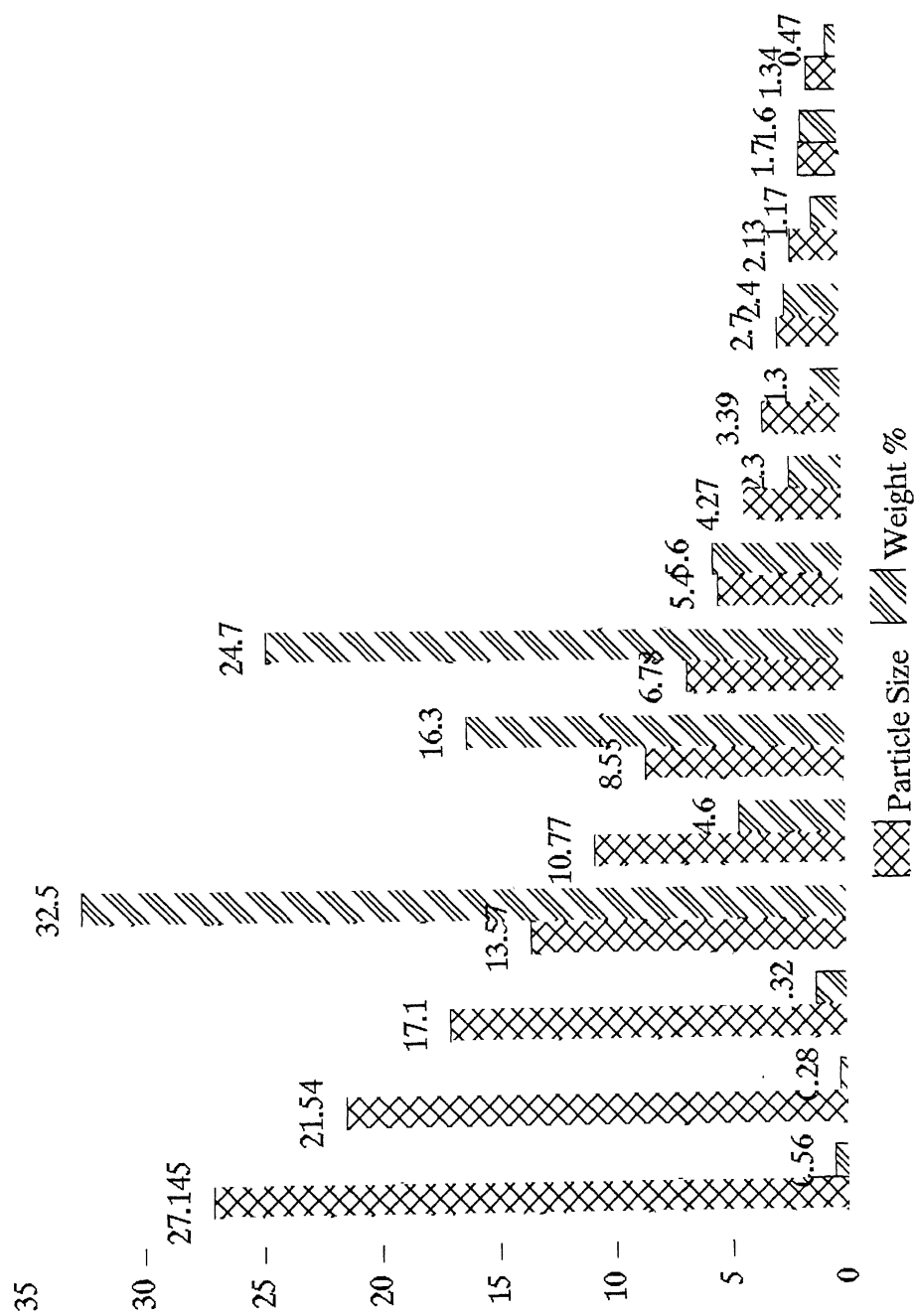
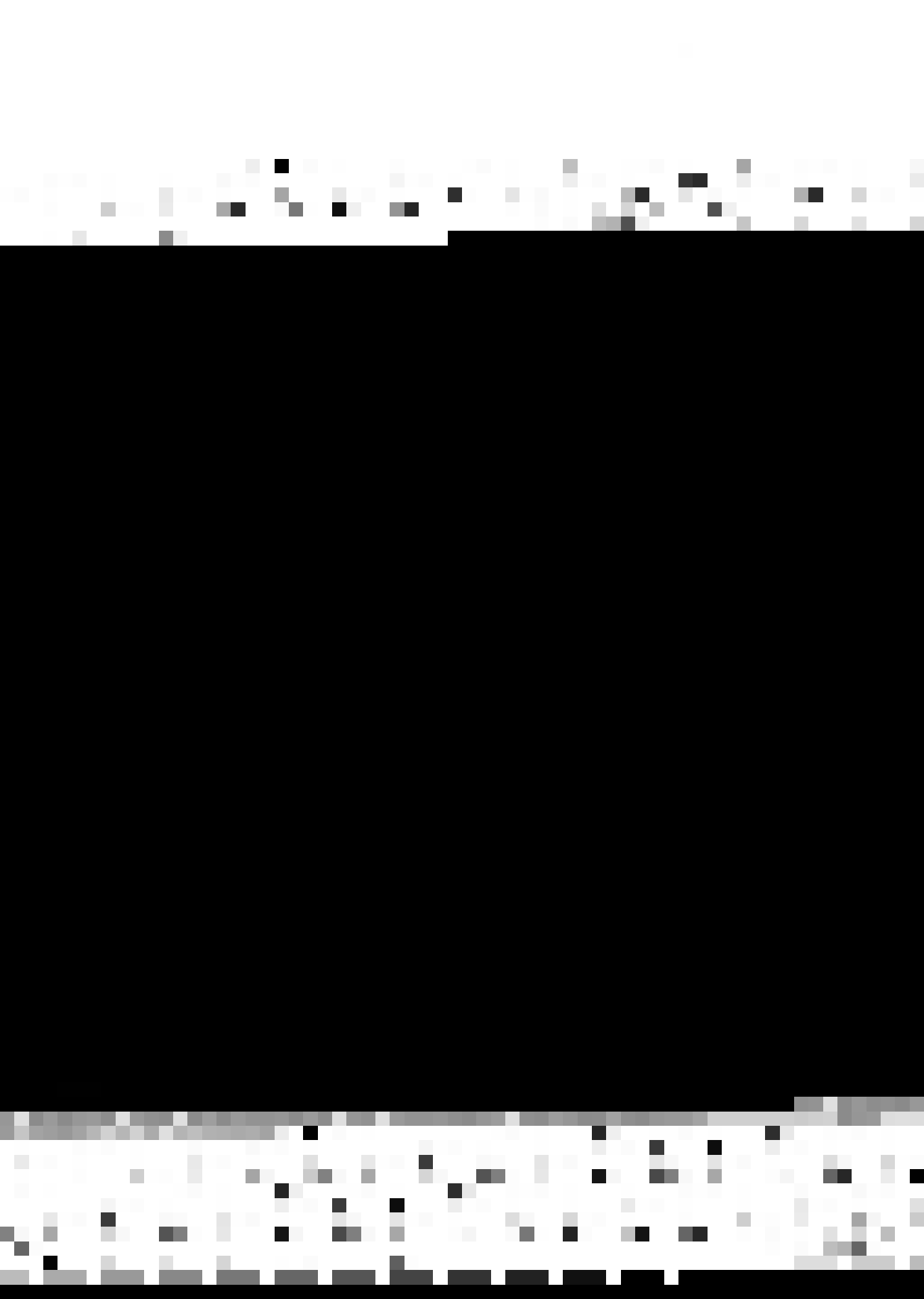


Fig 4.1 Particle size distribution of Diamond







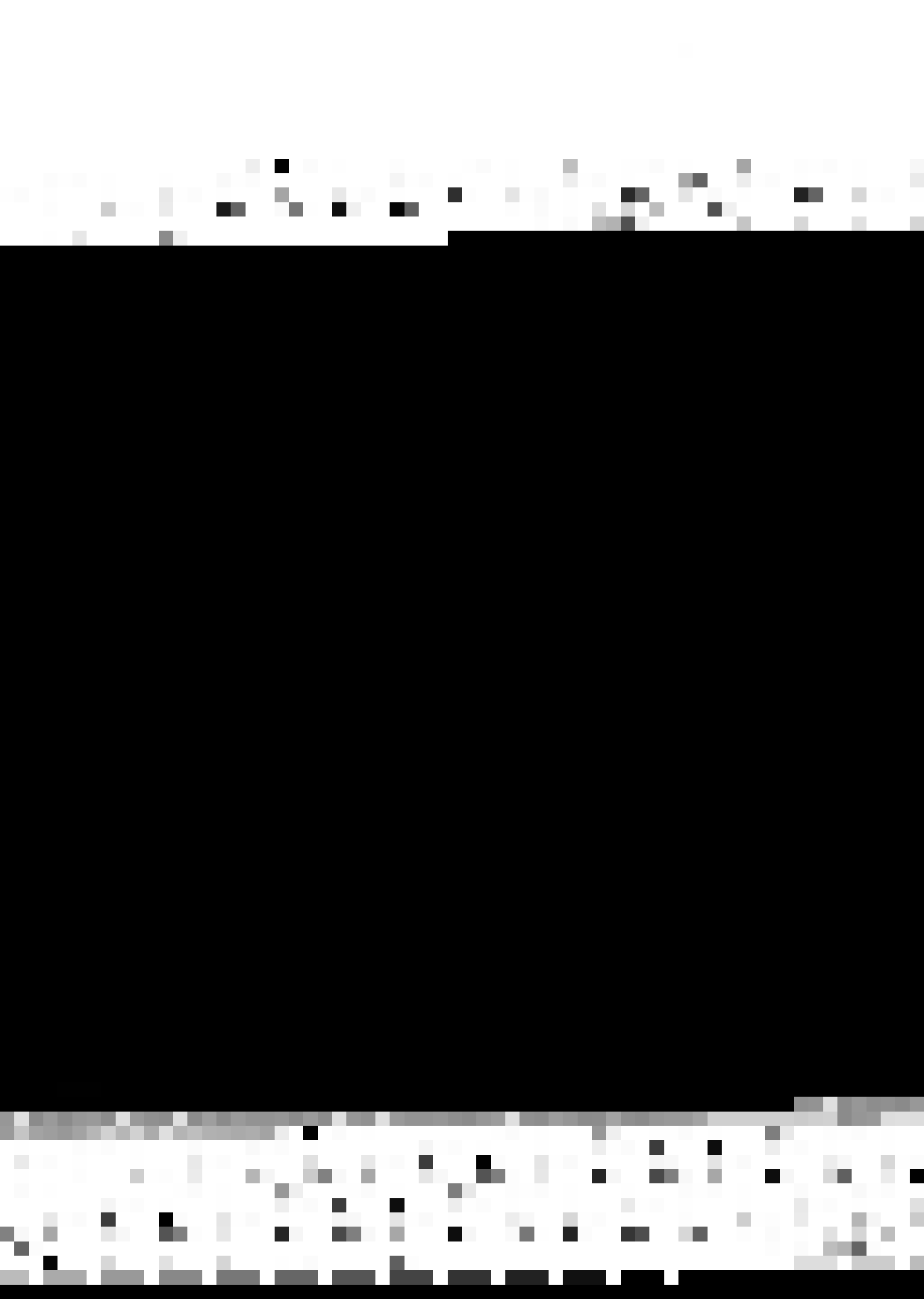




Fig 4.3 Particle size distribution of Nickel

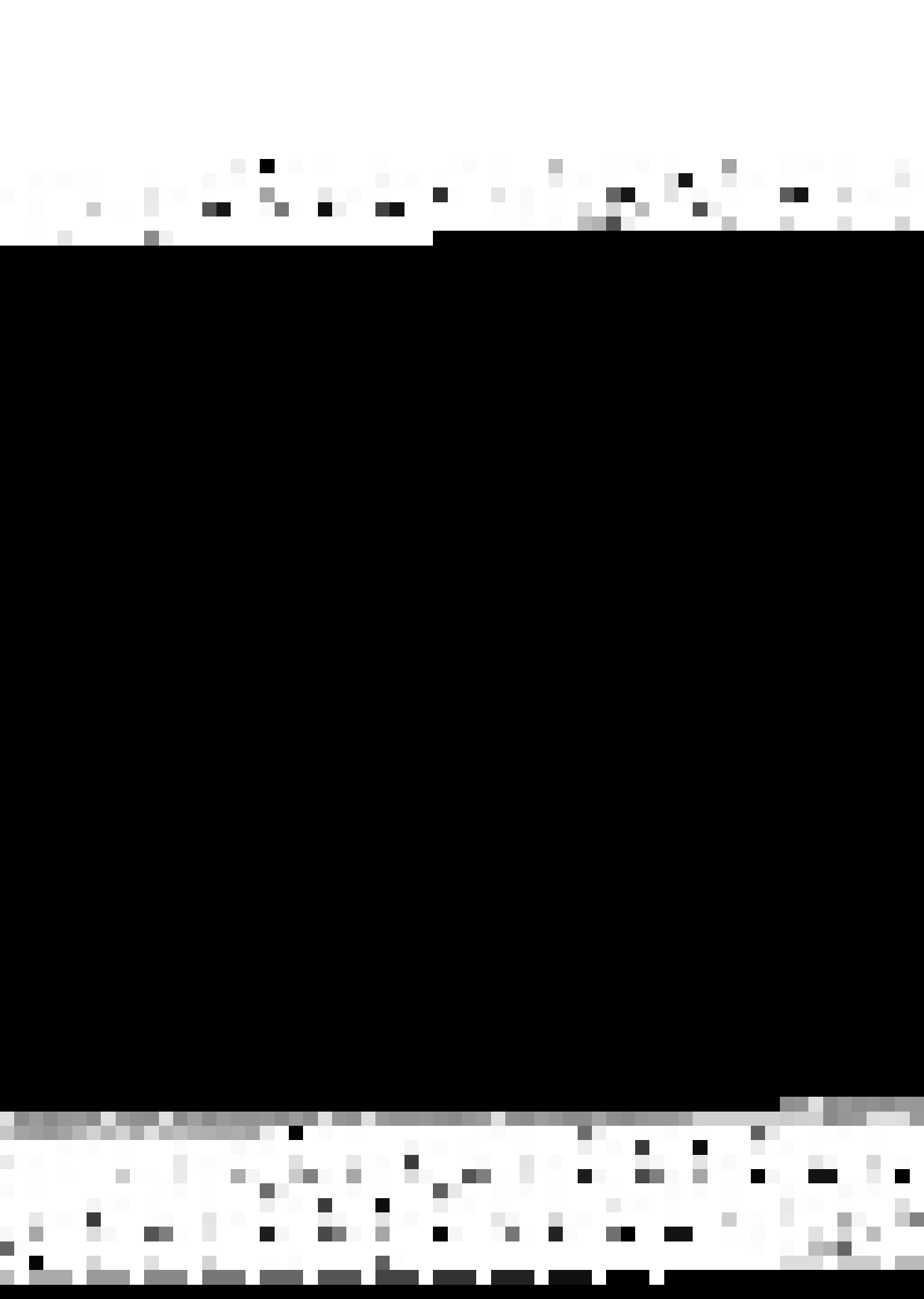


Table 4.1 Density of D-B composite pellet after cold compaction and sintering.

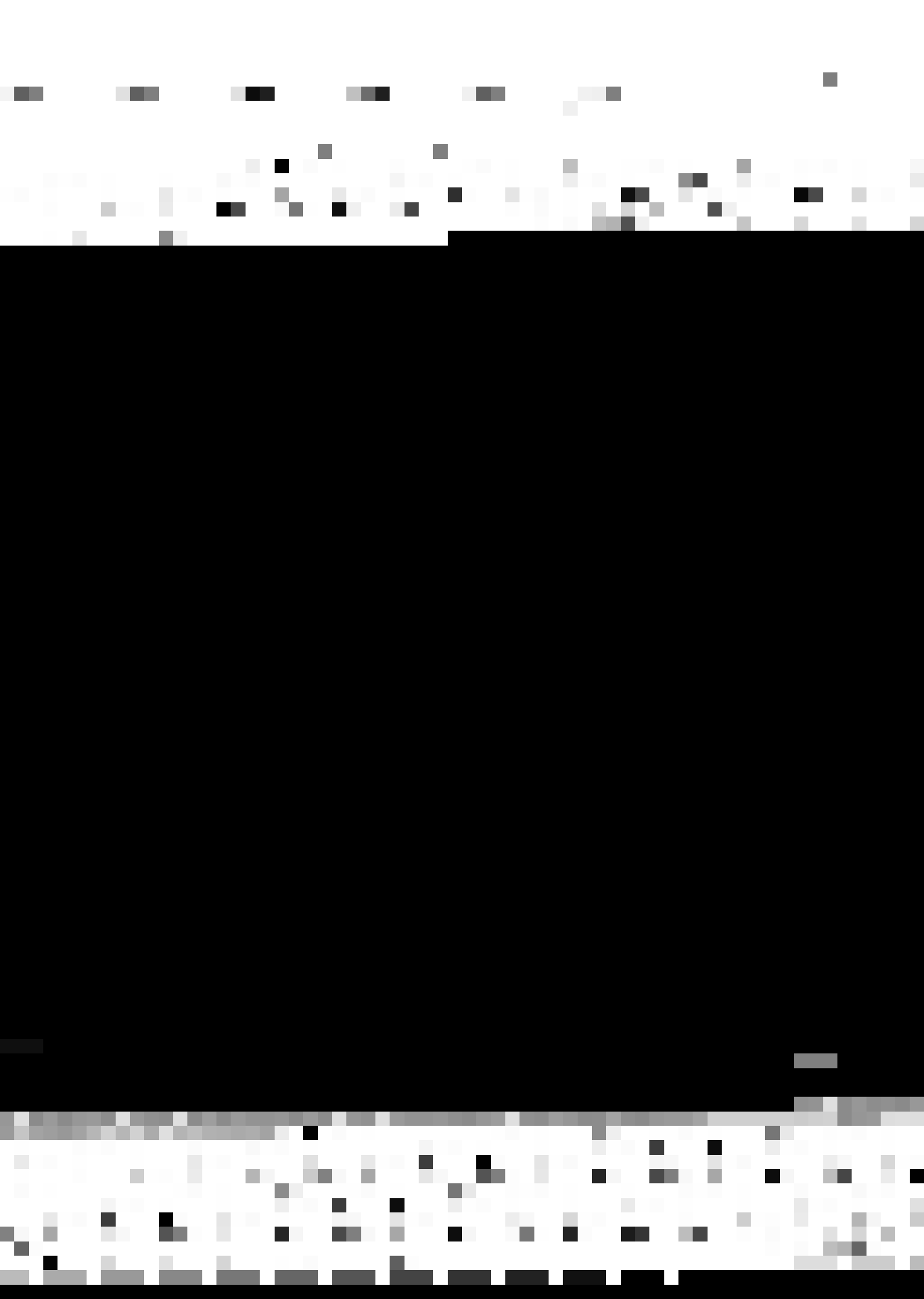
Composition	G.D after compaction at 350 Kg/cm <sup>2</sup>	% rel densfn.	S.D after sintered at 800°C for 2 hr.	% rel densfn.	Porosity of the final sintered sample
Diamond - Bronze (1:2)	3.2	55.6	3.51	60.2	39.80

\* Radius of the compact : 184 mm  
 Weight of the compact : 7.2 gm  
 Thickness of the compact: 5 mm

Table 4.2 Density of D-B and D-B with 4 wt% Ni composite pellet after hot pressing.

Sample Composition (wt%)	Theoretical Density (g/cc)	Holding Time (min)	Sintered Density (g/cc)	% rel densfn.
Diamond - Bronze in ratio 1:2	5.84	15	3.56	61.0
		30	3.62	62.0
		45	3.88	66.54
		60	3.88	66.54
Diamond - Bronze in ratio 1:2 with 4% Ni.	5.922	10	3.840	65.0
		20	3.966	67.0
		40	4.250	71.8
		60	4.263	72.0

\* Temperature: 820°C Pressure: 0.4 tons/inch<sup>2</sup>  
 Diameter of compact: 1.27 cm  
 Thickness of compact: 2.0 mm



further pursued and the experiments are carried out following the second alternative.

The results after hot pressing D-B composite material is shown in Table 4.2. Hot pressing was carried out at  $820^{\circ}\text{C}$  at a pressure of 0.4 tons/inch<sup>2</sup>. This pressure was the maximum attainable by the available hot press. After various trials, it was found out that holding time of 45 min was optimum. Increase in holding time greater than 45 min served no purpose. After hot pressing, the pellets had densities of 66.54 % of the theoretical. The hot pressing characteristics of D-B composite material is shown in Fig 4.4. It can be observed that the % porosity is reduced due to hot pressing when compared to that of samples obtained after cold compaction and sintering. Samples after hot pressing were comparatively stronger. Hot pressed D-B samples were subjected to thickness reduction by hot rolling. These pellets behaved better during hot rolling and it was possible to give a total thickness reduction 60 %. Density and porosity of hot pressed D-B composite material after various thickness reduction by hot rolling is summarised in Table 4.3. Densification behaviour of D-B composite material can be observed from Fig.4.6. Density increases from 66.54 of theoretical to 79.90 of theoretical at 60% thickness reduction. As a result, porosity decreased from 33.46% to 20.10%. This can be seen from Fig 4.8.

Thickness reduction greater than 60%, was not possible due to severe edge cracking which sometime almost extended to the center, due to the small size of the samples. The rolled strips after 60% thickness reduction also lacked adequate strength.

~~It was earlier reported~~ that due to the addition of Ni, there will be some sort of chemical reaction at the diamond-matrix interface. Thus with the aim to increase the bond strength and ductility 4 wt% Ni was incorporated



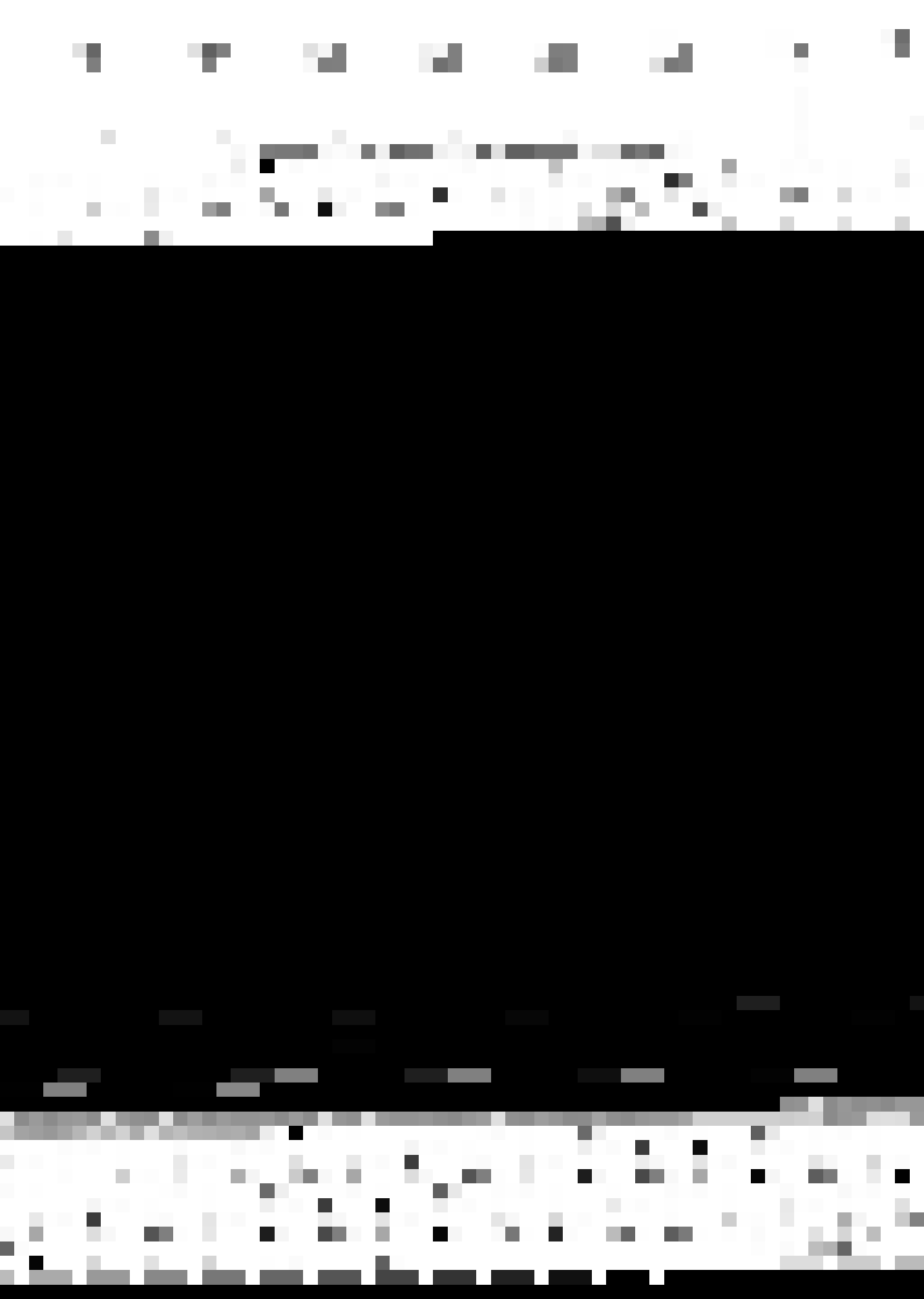


Table 4.3 Density and porosity of D-B composite pellet at various thickness reduction by hot rolling.

Sample	% Total Deformation	Density (g/cc)	% rel densfn.	% Porosity
H.P.	0	3.88	66.54	33.46
Pass-1	15	4.05	69.50	30.50
Pass-2	23	4.14	71.03	28.97
Pass-3	35	4.30	73.70	26.30
Pass-4	45	4.43	75.90	24.1
Pass-5	60	4.66	79.90	20.10

\* Initial thickness : 2 mm  
Final thickness : 0.8 mm

Table 4.4 Density and porosity of D-B composite pellet with 4 wt% Ni at various thickness reduction by hot rolling.

Sample	% Total Deformation	Density (g/cc)	% rel densfn.	% Porosity
H.P.	0	4.25	71.8	28.2
Pass-1	10	4.34	73.4	26.6
Pass-2	15	4.48	75.8	24.2
Pass-3	30	4.60	77.7	22.3
Pass-4	38	4.77	80.6	19.4
Pass-5	44	4.89	82.6	17.4
Pass-6	51	5.03	85.1	14.9
Pass-7	62	5.181	87.5	12.5
Pass-8	70	5.34	90.2	9.8

\* Initial thickness : 2 mm  
Final thickness : 0.6 mm



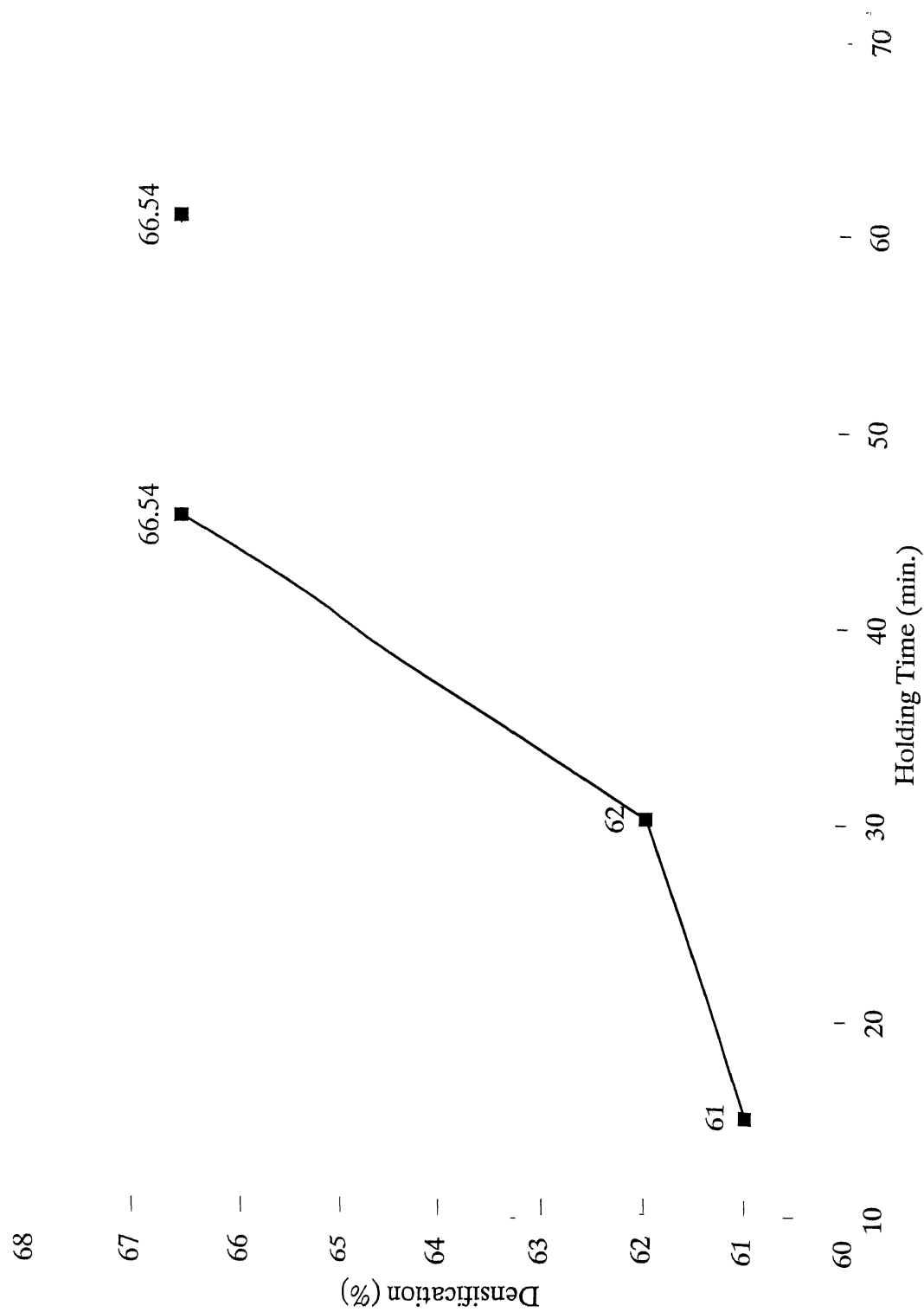
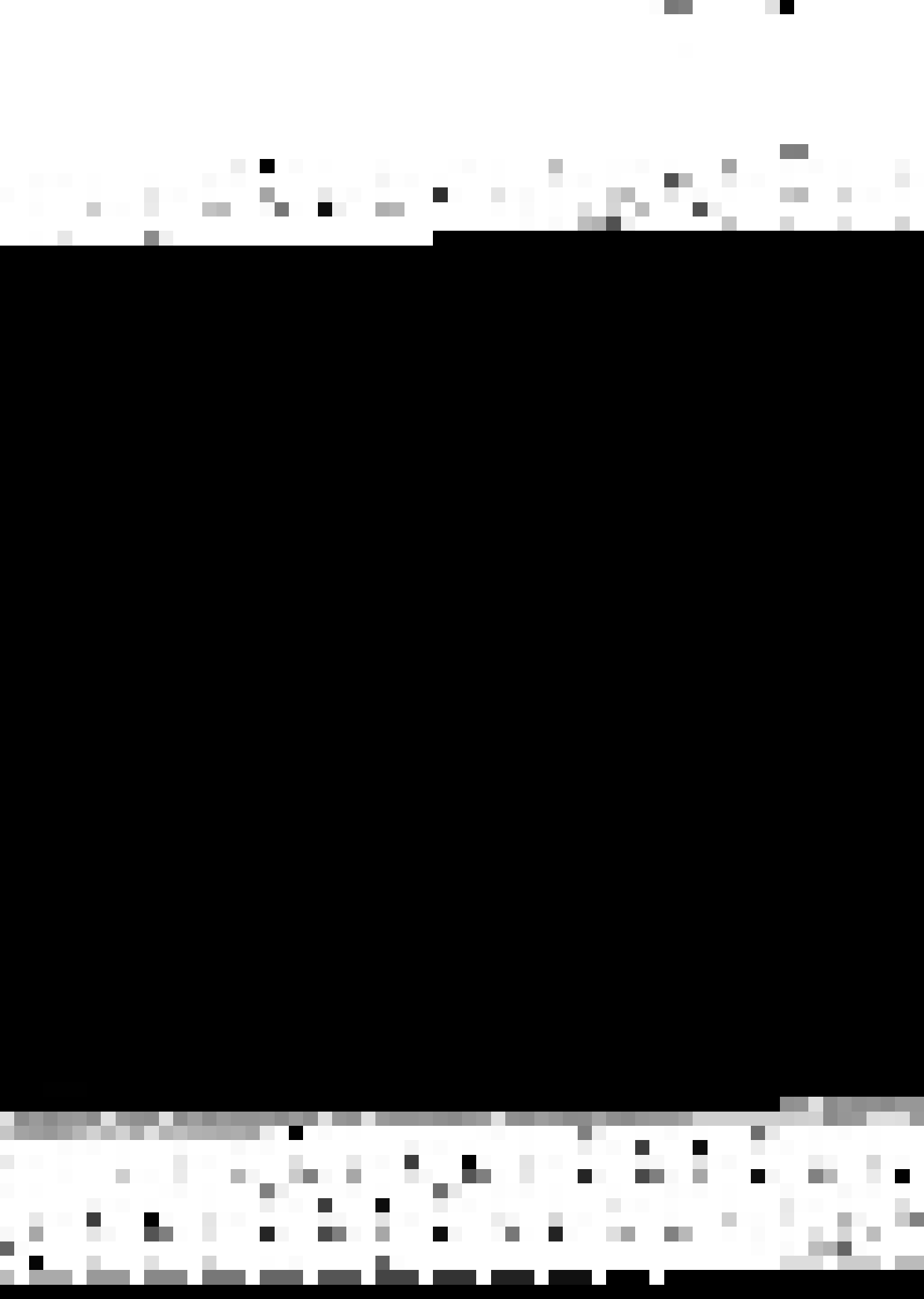


Fig 4.4 Hot pressing characteristic of D-B composite material



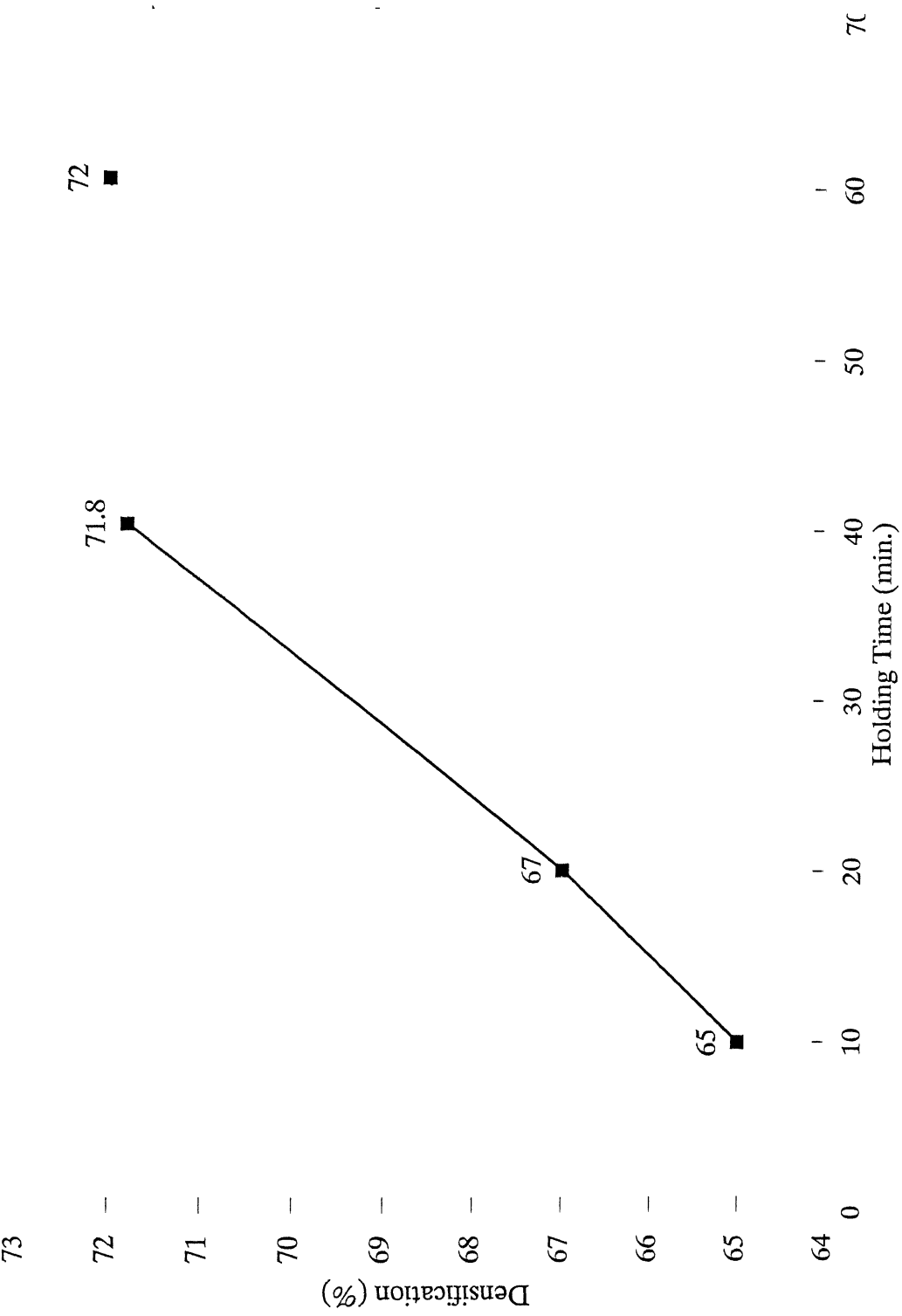
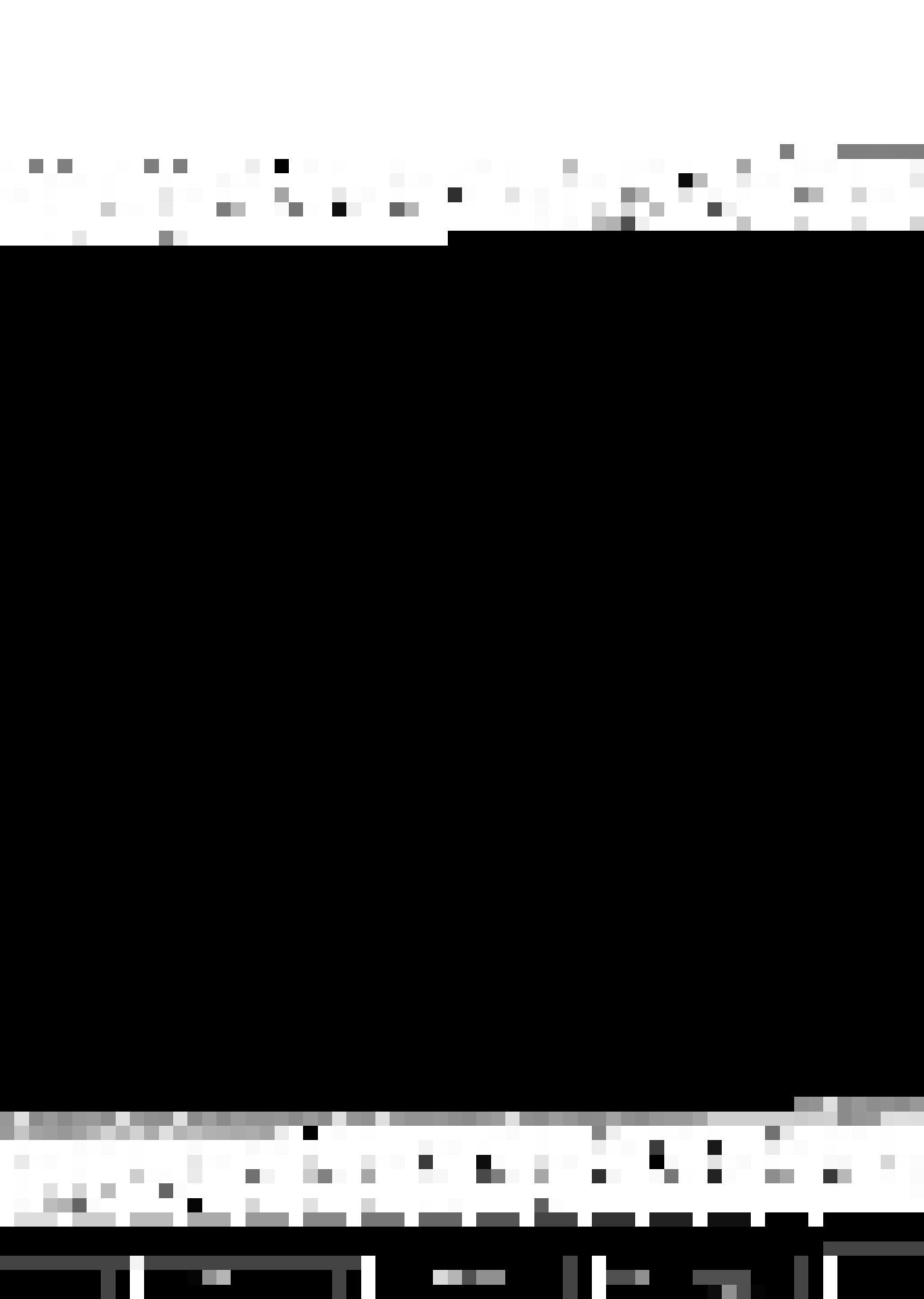


Fig 4.5 Hot pressing characteristic of D-B-4 wt% Ni composite material



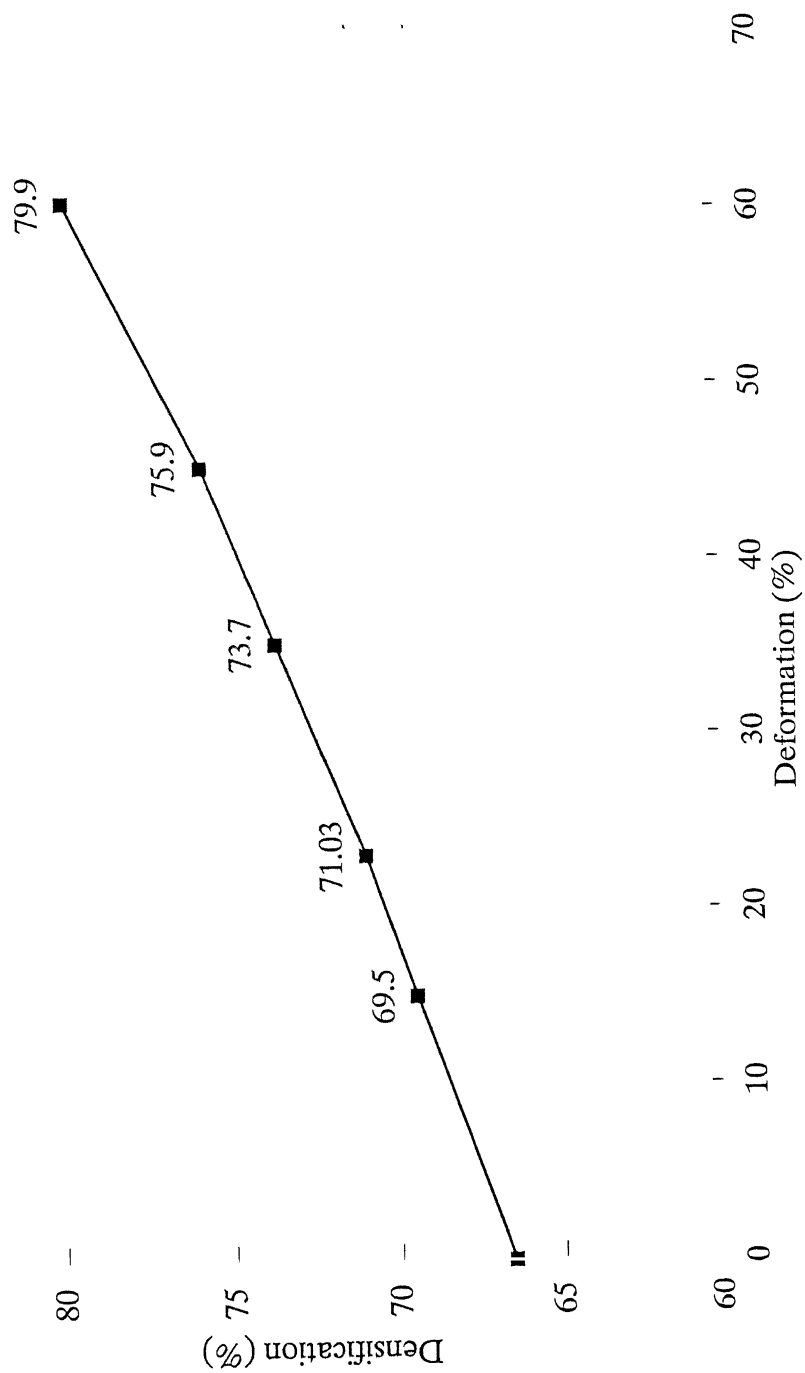
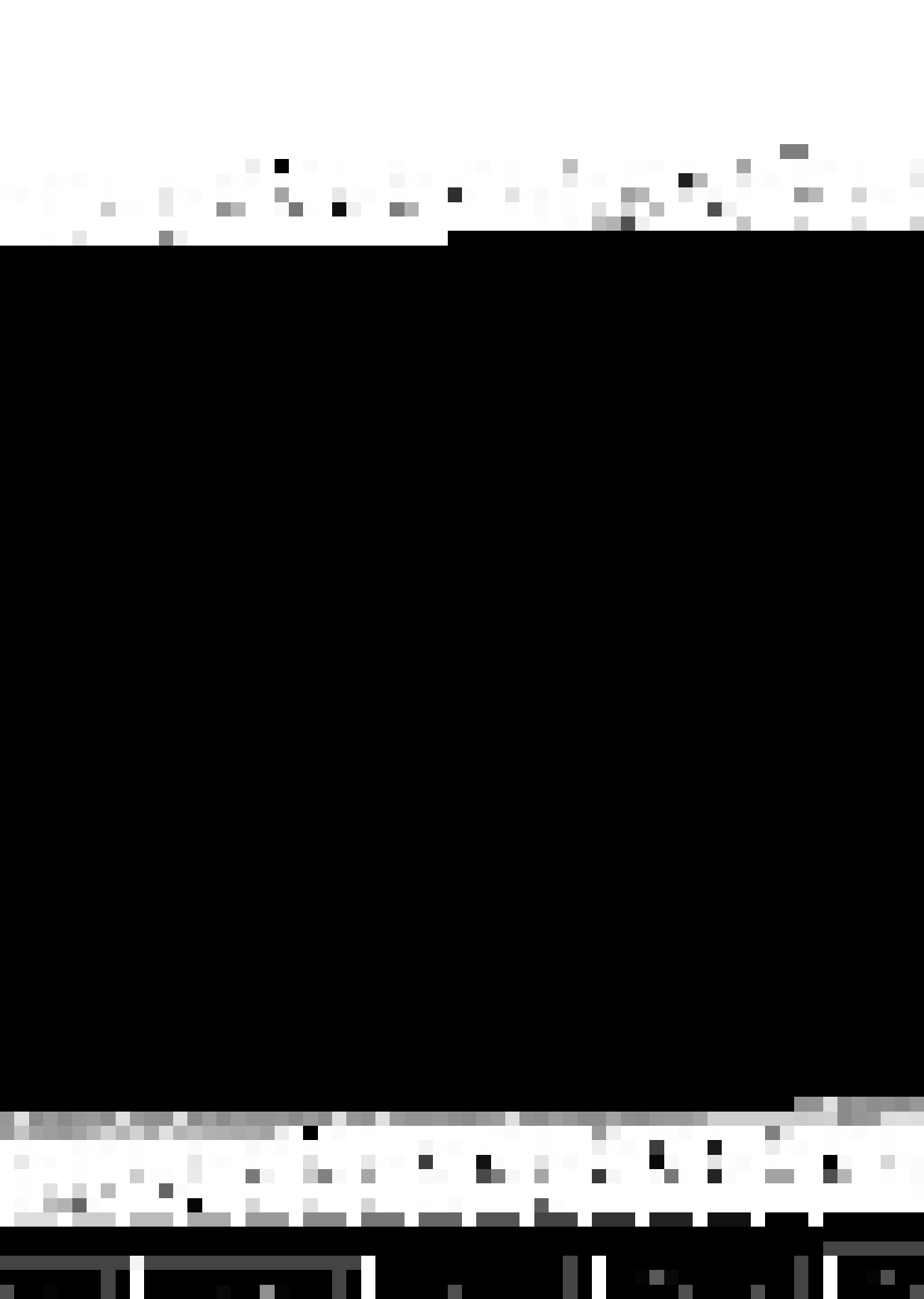


Fig 4.6 Effect of hot rolling deformation on the densification behaviour of D-B composite pellet





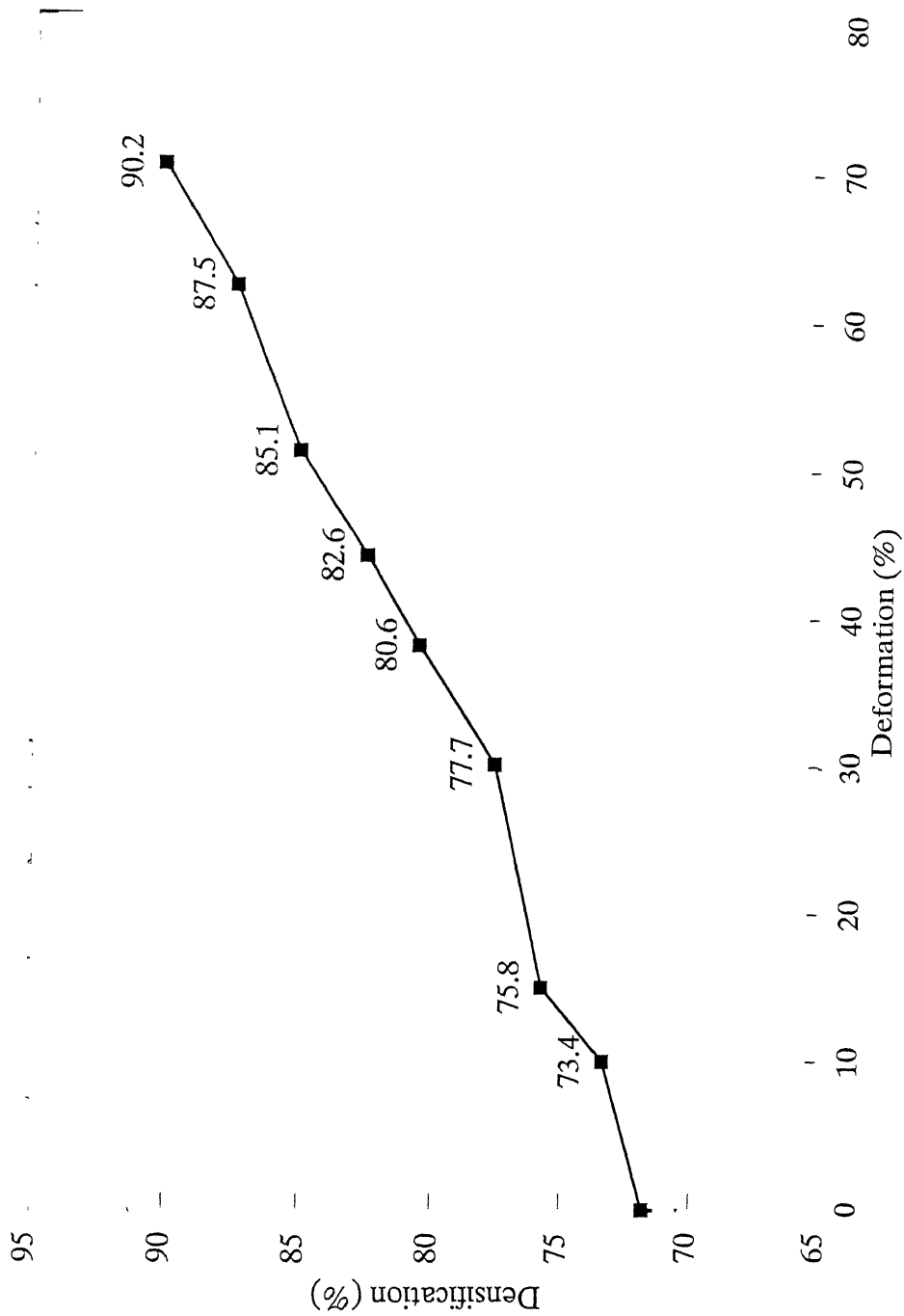
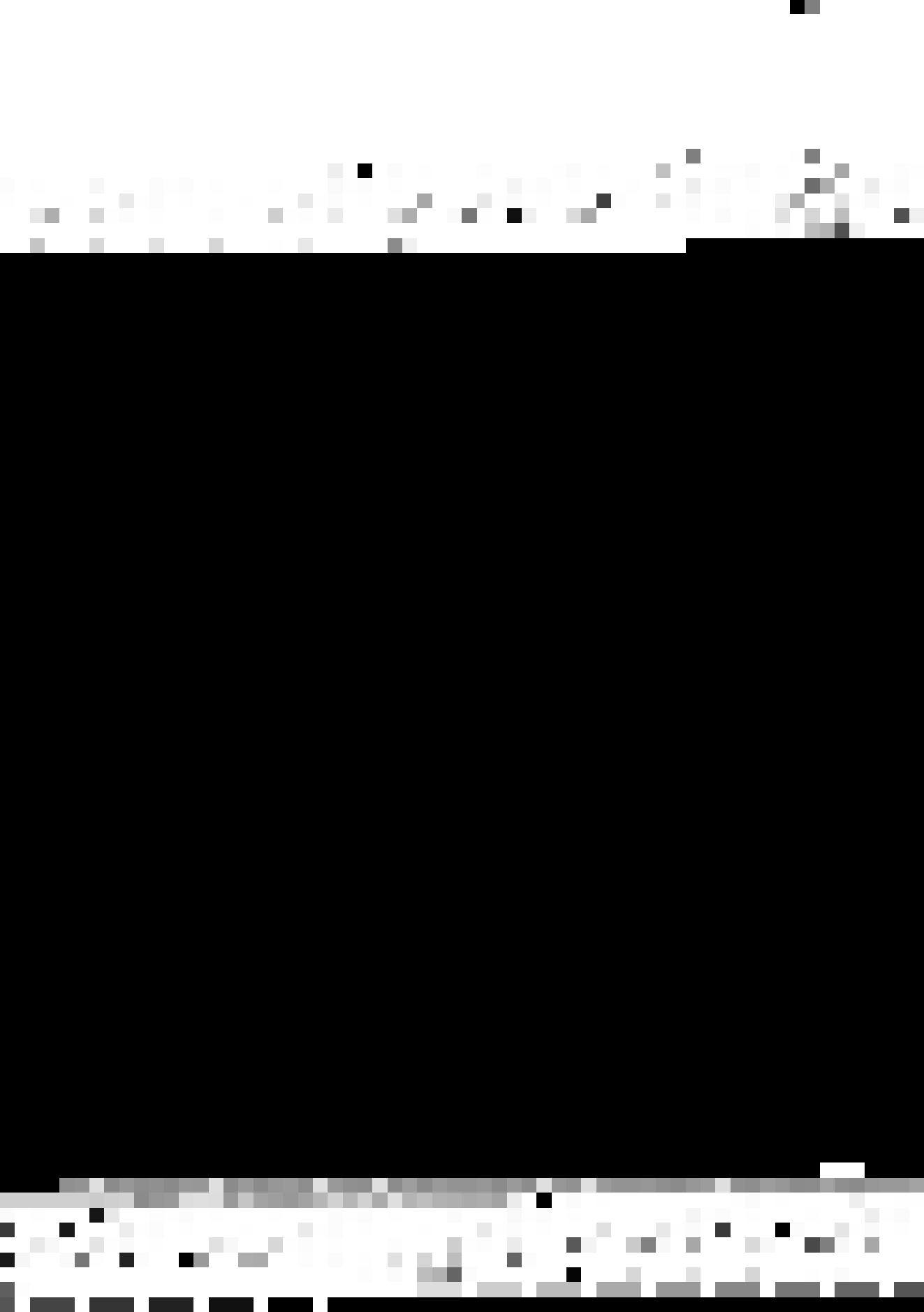


Fig 4.7 Effect of hot rolling deformation on the densification behaviour of D-B-4 wt% Ni composite pellet



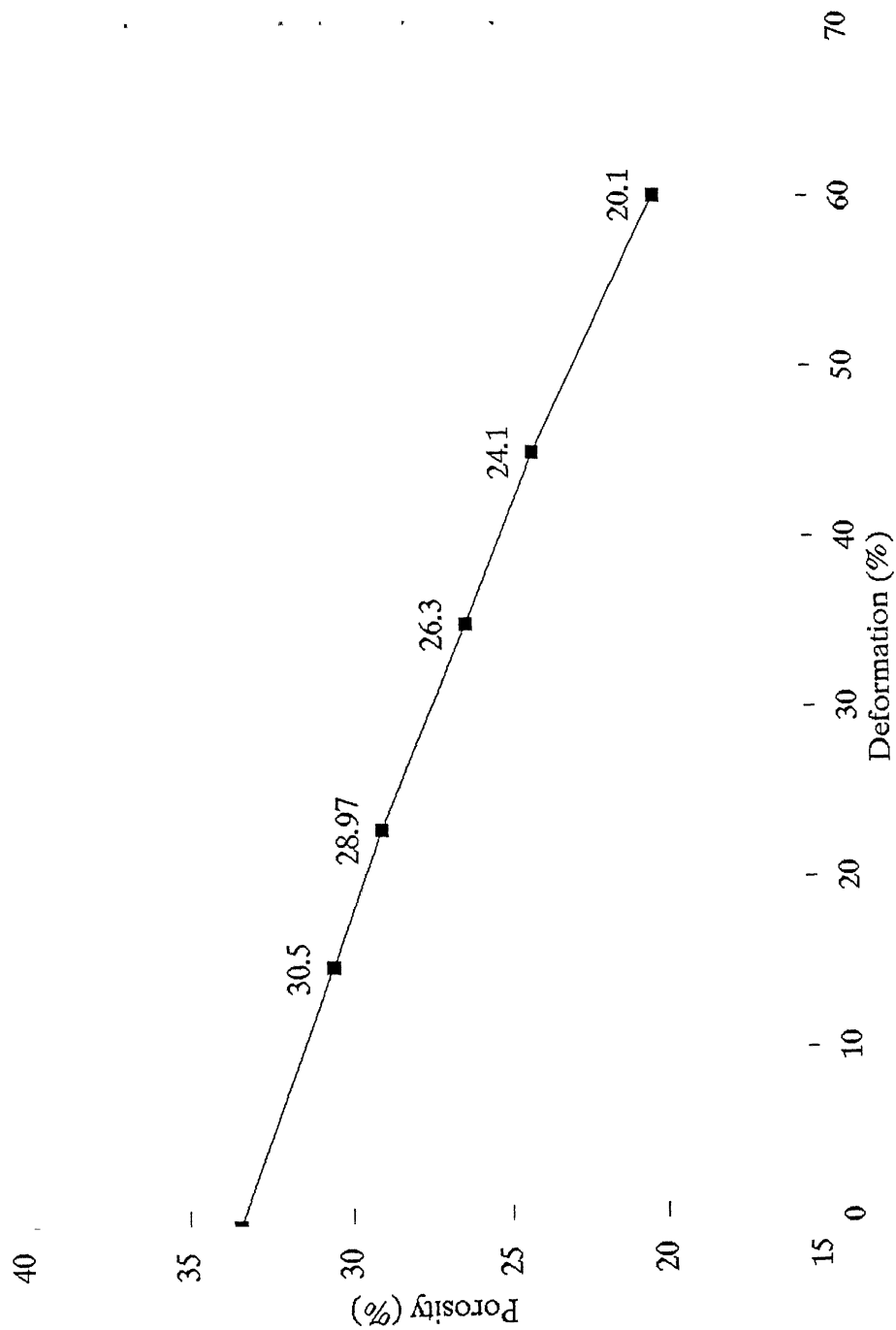
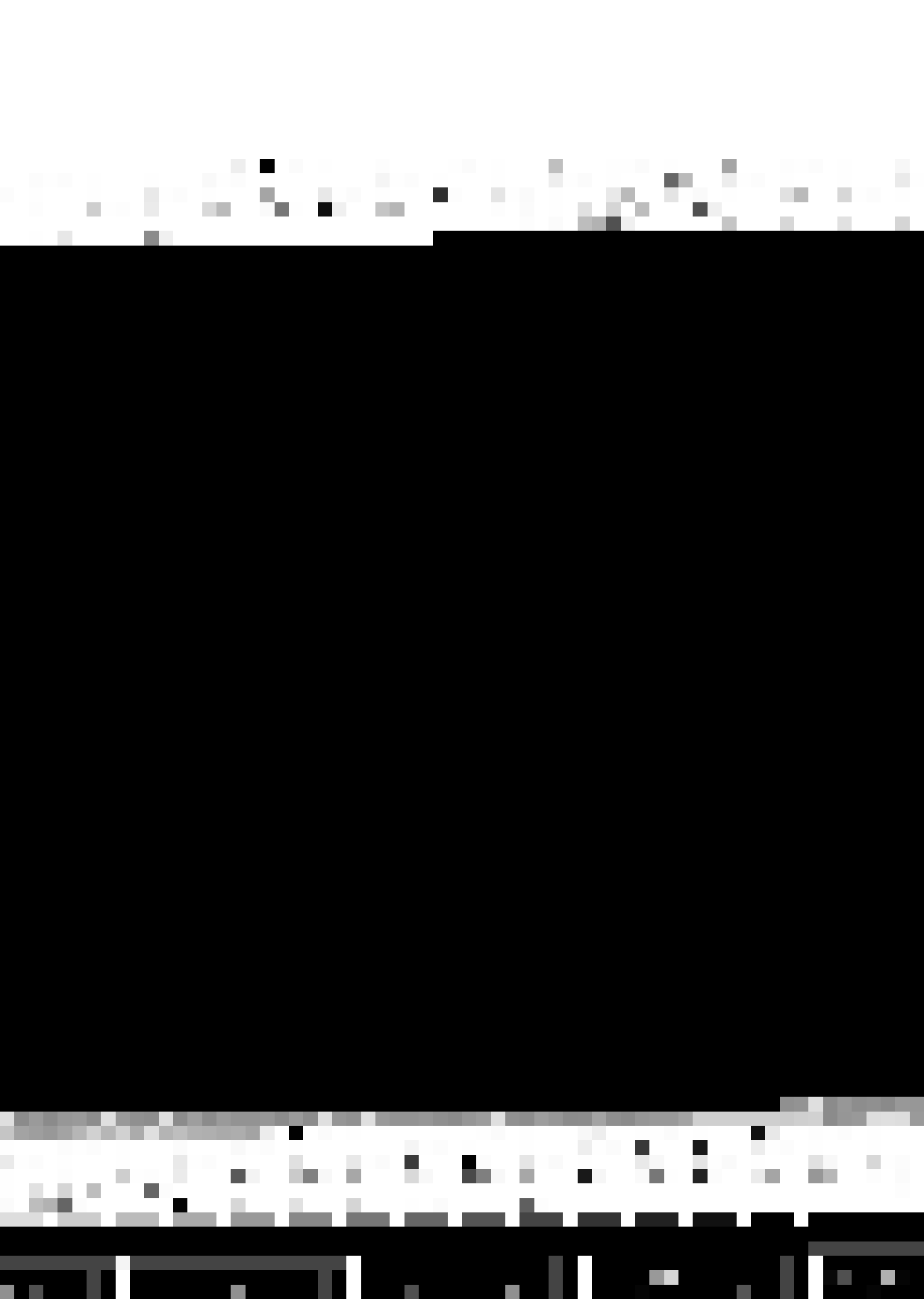
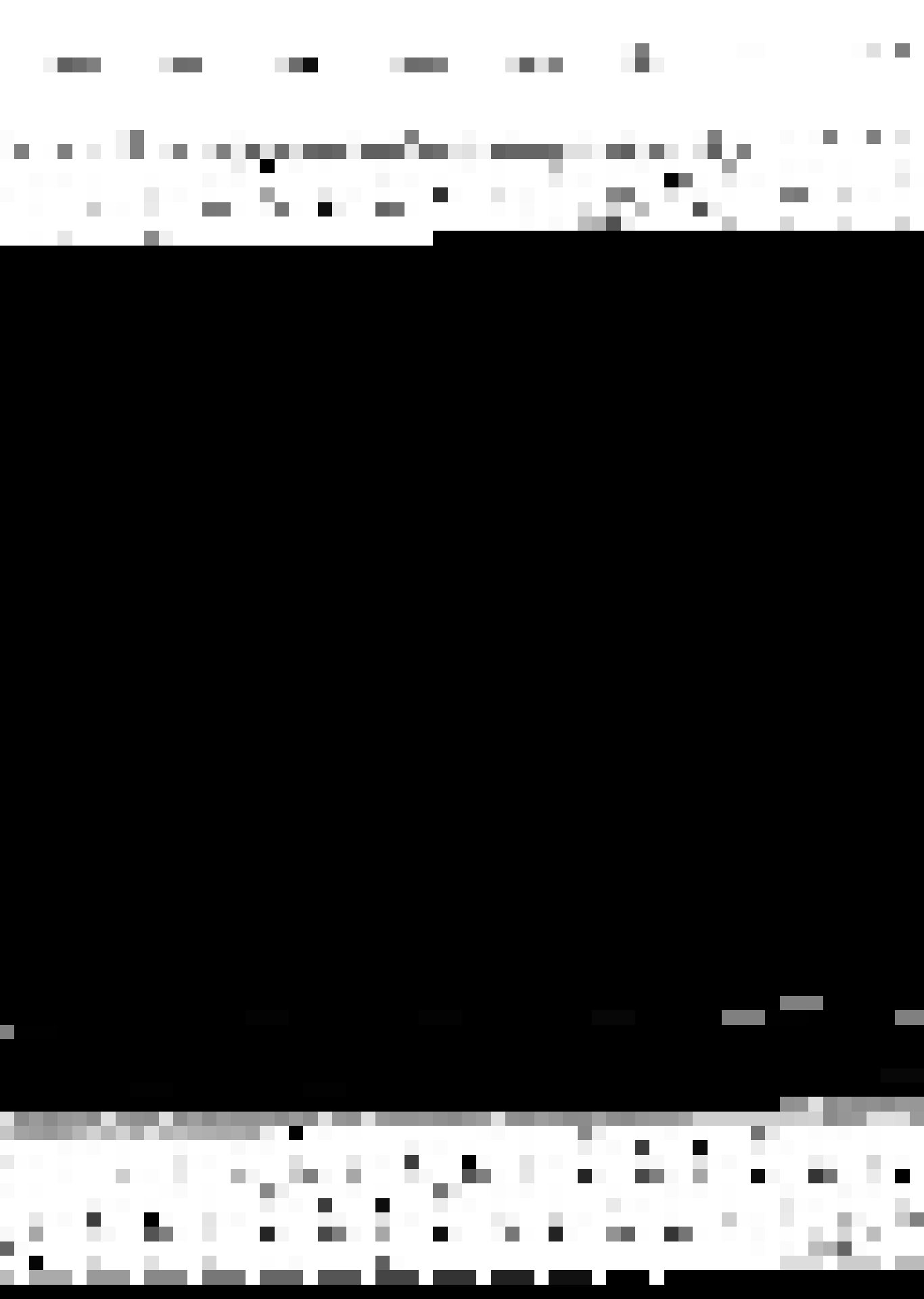


Fig 4.8 Effect of hot rolling deformation on the porosity of the D-B composite pellet



in the D-B mixture. D-B-4 wt% Ni samples were hot pressed at 820°C for 60 min. In this case, holding time of 60 min was found to be optimum. Density after hot pressing was found to be 4.263 which was 72% of the theoretical density. Fig 4.5 shows the hot pressing characteristic of D-B-4 wt% Ni composite pellet and the results are summarised in Table 4.2. The hot pressed pellets is again subjected to thickness reduction by hot rolling. Density and porosity at various thickness deformation is given in Table 4.4. Densification behaviour of D-B-4 wt% Ni composite material is shown in Fig 4.7 and the resulting decrease in porosity in Fig 4.9. Total thickness reduction of 70% by hot rolling was possible and porosity decreased from 28.2 to 9.8%. Edge cracking was considerably less compared to D-B composite strips and the rolled strips were sufficiently strong. Efficiency of densification was calculated for both D-B composite material and D-B-4 wt% Ni and results are presented in table 4.5. Efficiency of densification is plotted with respect to thickness reduction and relative density and this can be observed from Fig 4.10 and Fig 4.11. The efficiency of densification for D-B-4 wt% Ni is better than D-B composite material. Amount of densification of hot pressed and rolled samples are presented in the form of histogram in Fig 4.23. Diamond-Copper interfaces are weak because no chemical interactions occur and bonding is due to Van der Waals forces only. Ni was added to D-B composite mixture to increase the bond strength. The increased strength of the bond matrix was due to C-Ni bonding which enhances the diamond interface bond strength.

Amount of porosity before hot rolling is also a important factor to be considered. This should be reduced as far as possible. Lower the amount of porosity, stronger will the samples and hence better will be its behaviour during hot rolling. Density is one of the most important properties which should be taken into account while processing the



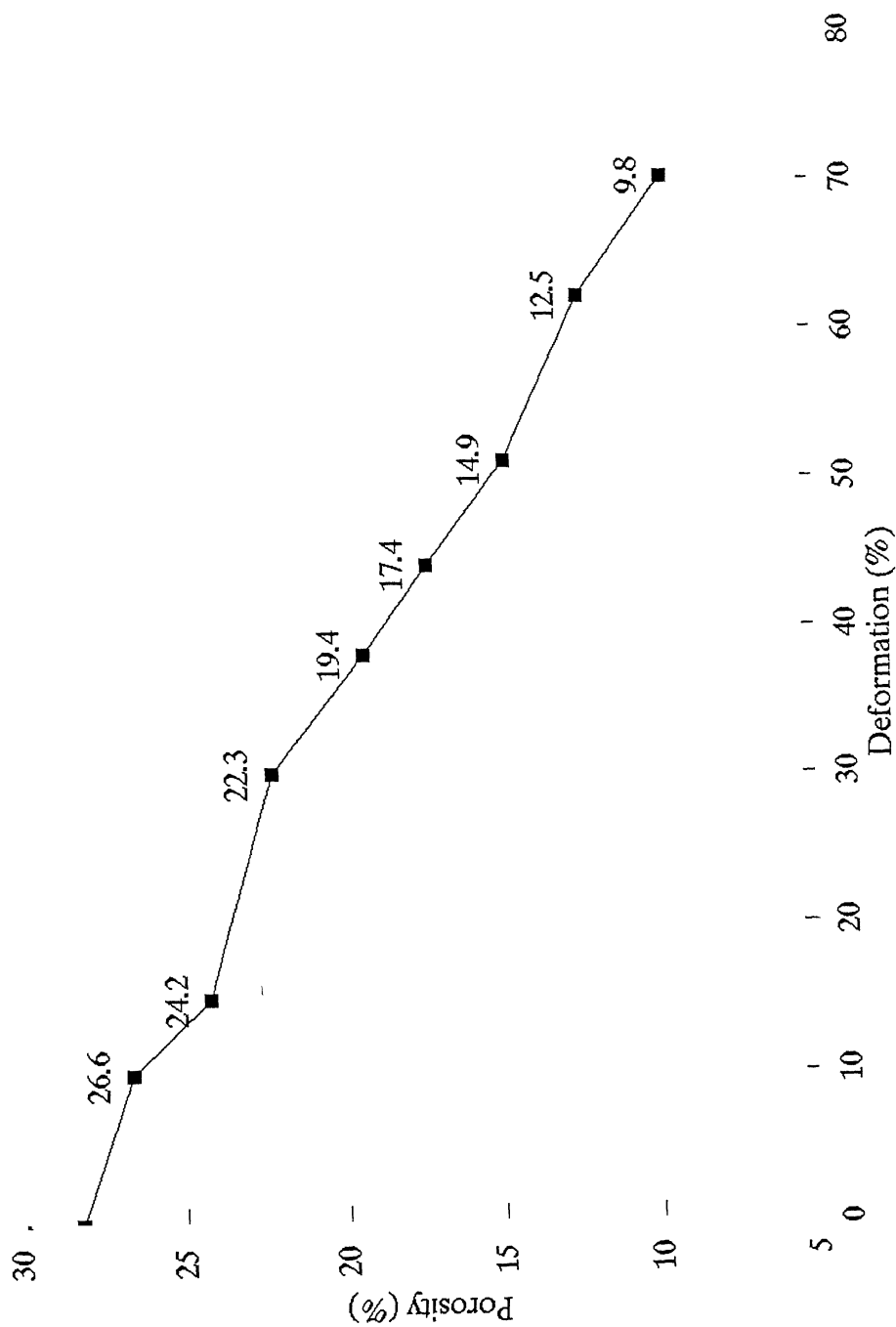


Fig 4.9 Effect of hot rolling deformation on the porosity of the D-B-4 wt%

Ni composite pellet



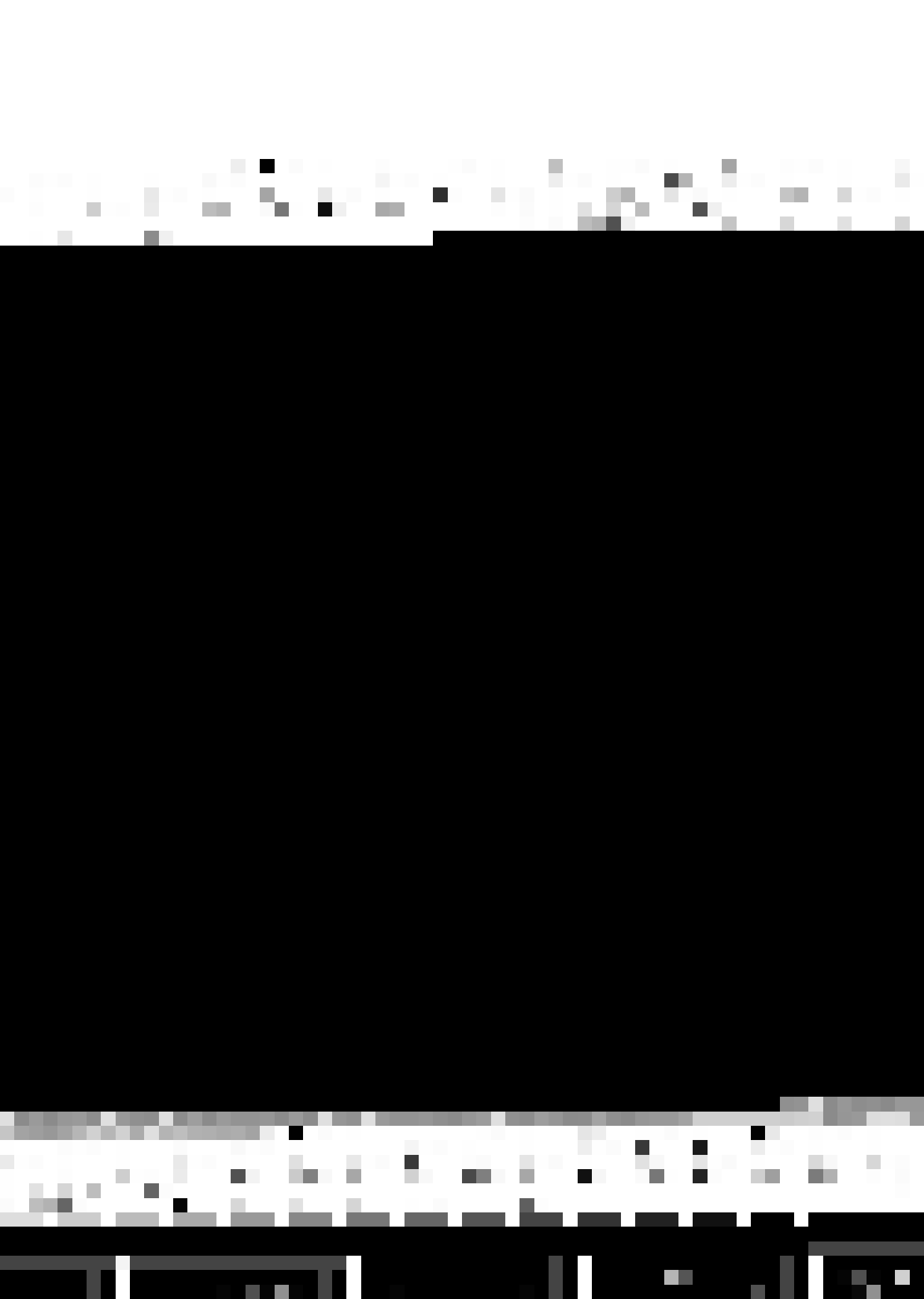


Table 4.5 Efficiency of densification for D-B and D-B with 4 wt% Ni at different thickness reductions.

Sample Composition	% Reduction, R	Relative density	E <sub>1</sub> (%)	E <sub>2</sub> (%)
D-B in ratio 1:2	15	0.6950	8.67	19.40
	23	0.7103	13.20	19.35
	35	0.7370	21.40	20.54
	45	0.7590	28.06	20.92
	60	0.7990	39.80	22.28
D-B in ratio 1:2 with 4 wt% Ni	10	0.734	5.40	15.20
	15	0.758	13.80	26.10
	30	0.777	20.90	19.80
	38	0.806	31.30	23.10
	44	0.826	38.32	24.60
	51	0.851	46.70	25.82
	62	0.875	55.74	25.36
	70	0.902	65.20	26.26

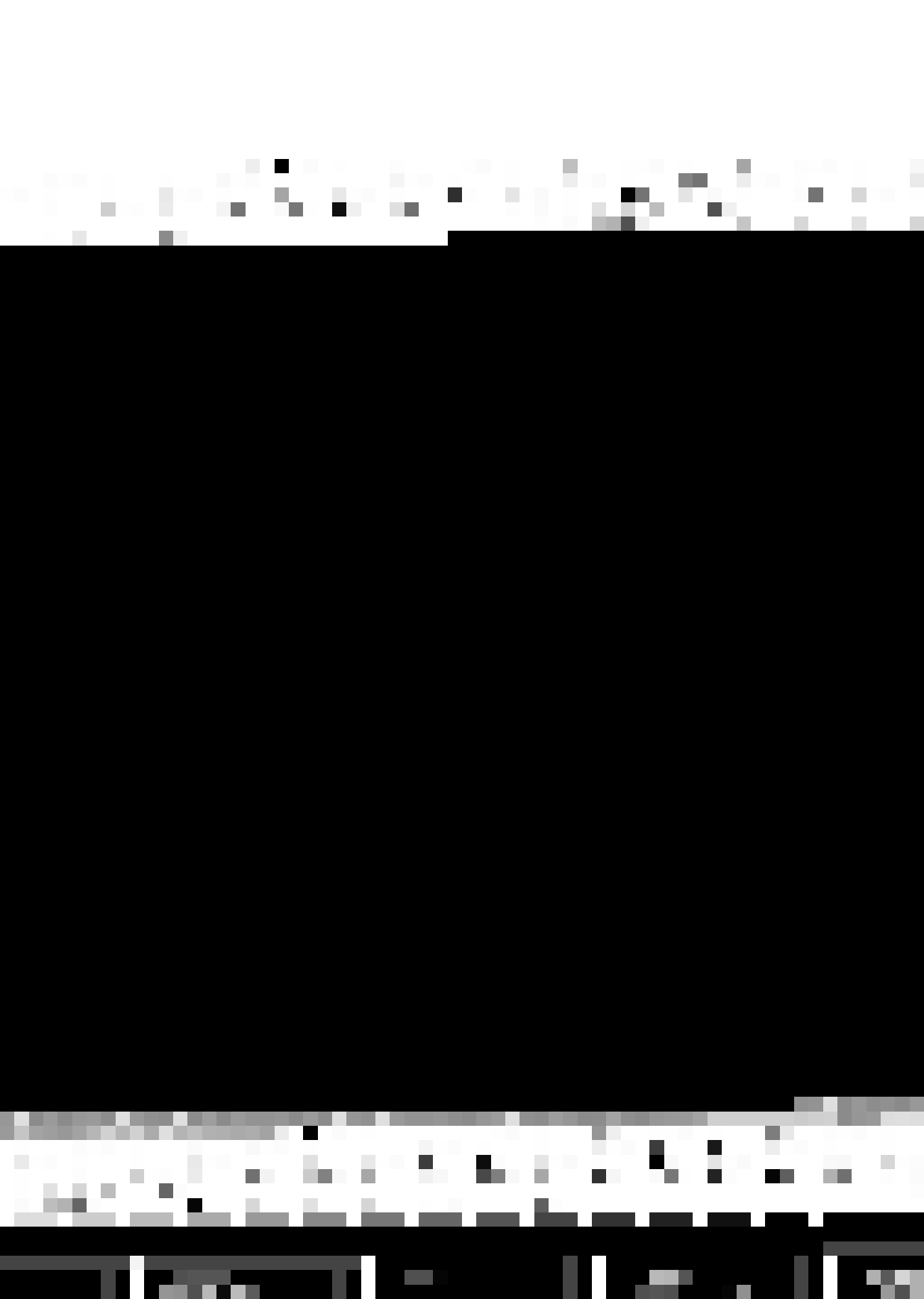
$$\begin{aligned}
 \text{**} \quad E_1 &= \frac{\rho_{HR} - \rho_0}{\rho_S - \rho_0} \times 100 & E_2 &= \frac{\rho_{HR} - \rho_0}{\rho_S \cdot R} \times 100
 \end{aligned}$$

where, E<sub>1</sub> & E<sub>2</sub> = Efficiency of densification

$\rho_{HR}$  = Hot rolled density

$\rho_S$  = Theoretical density

$\rho_0$  = Hot pressed density



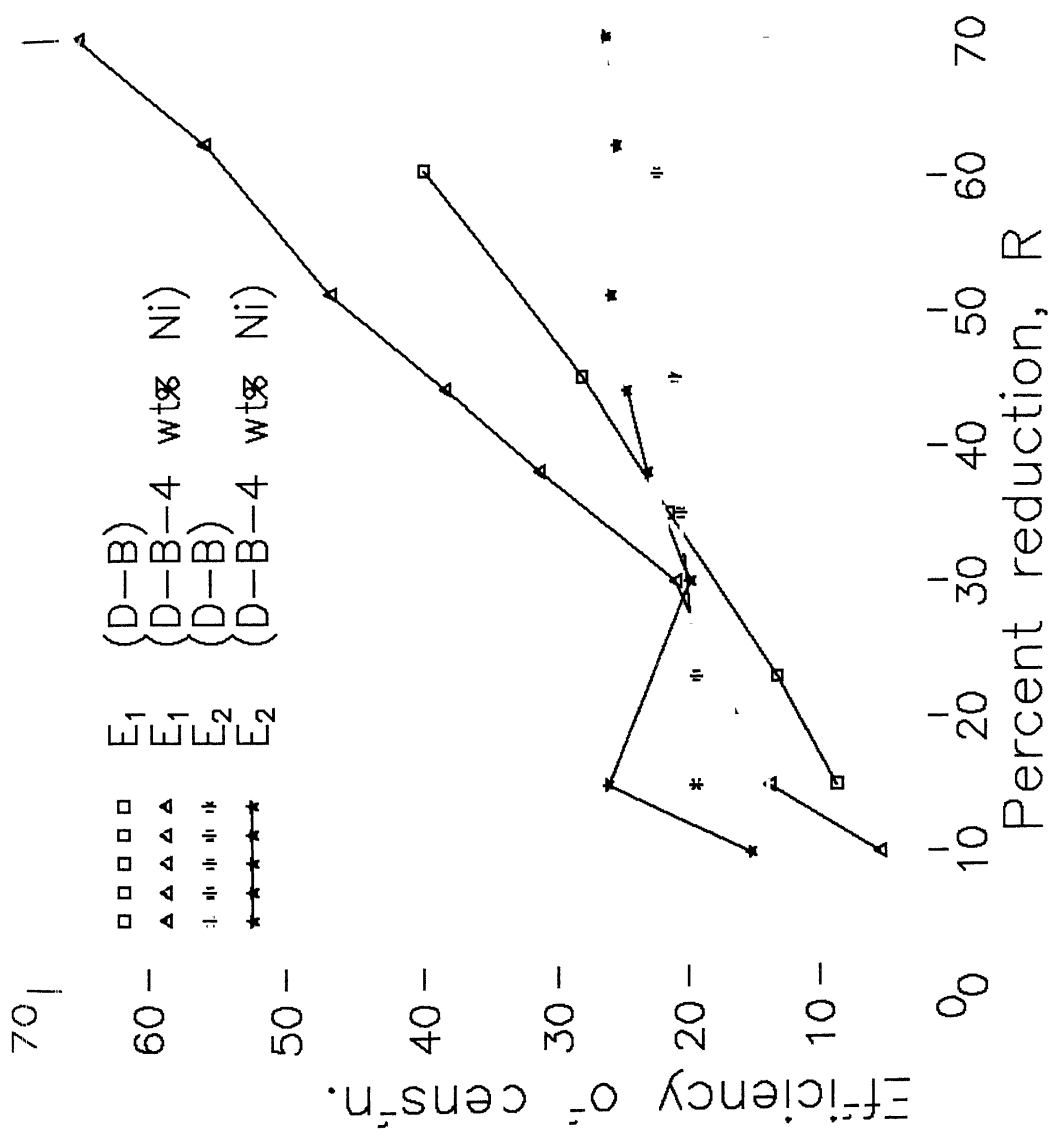
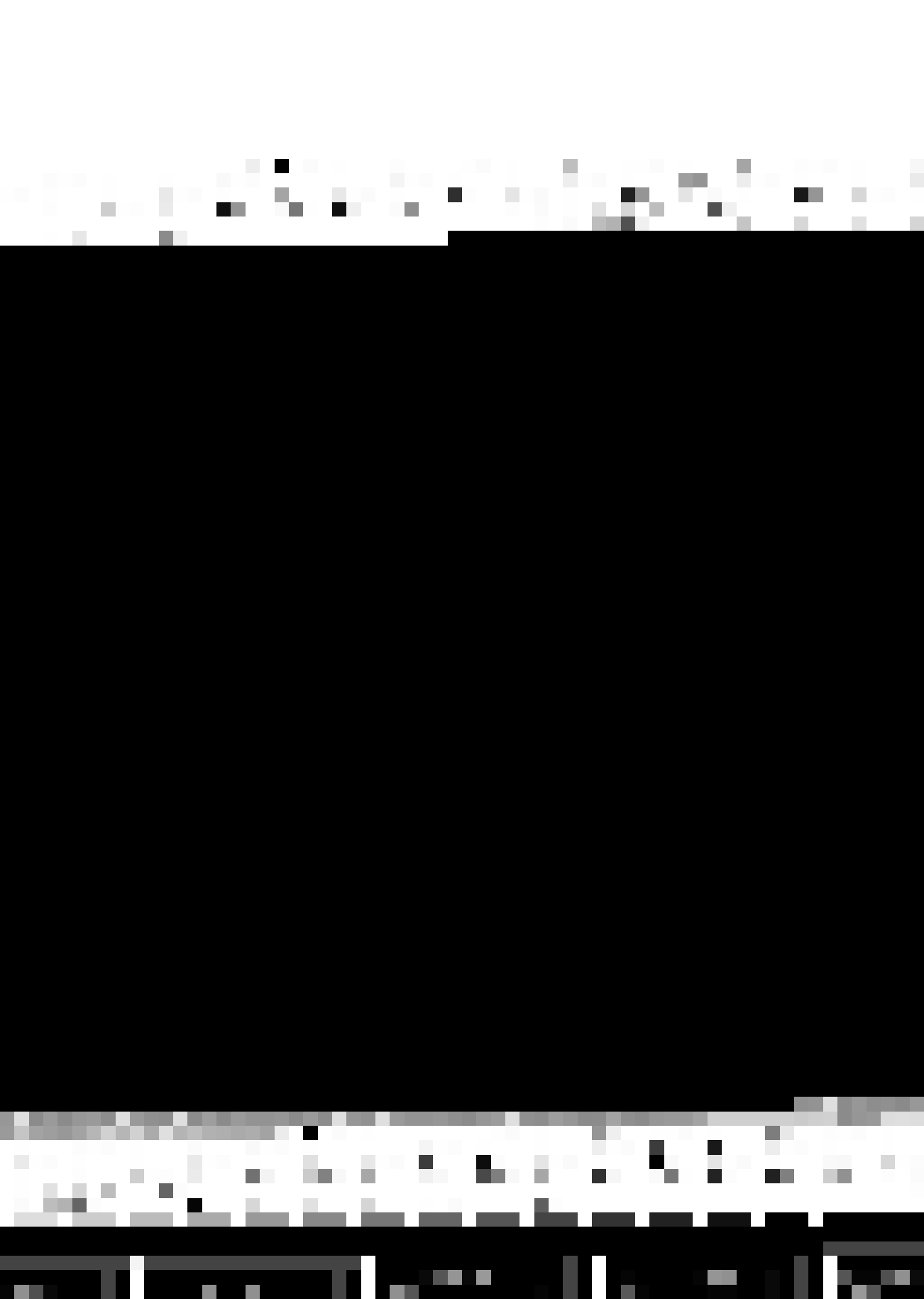


Fig 4.10 Efficiency of densification with respect to percent reduction



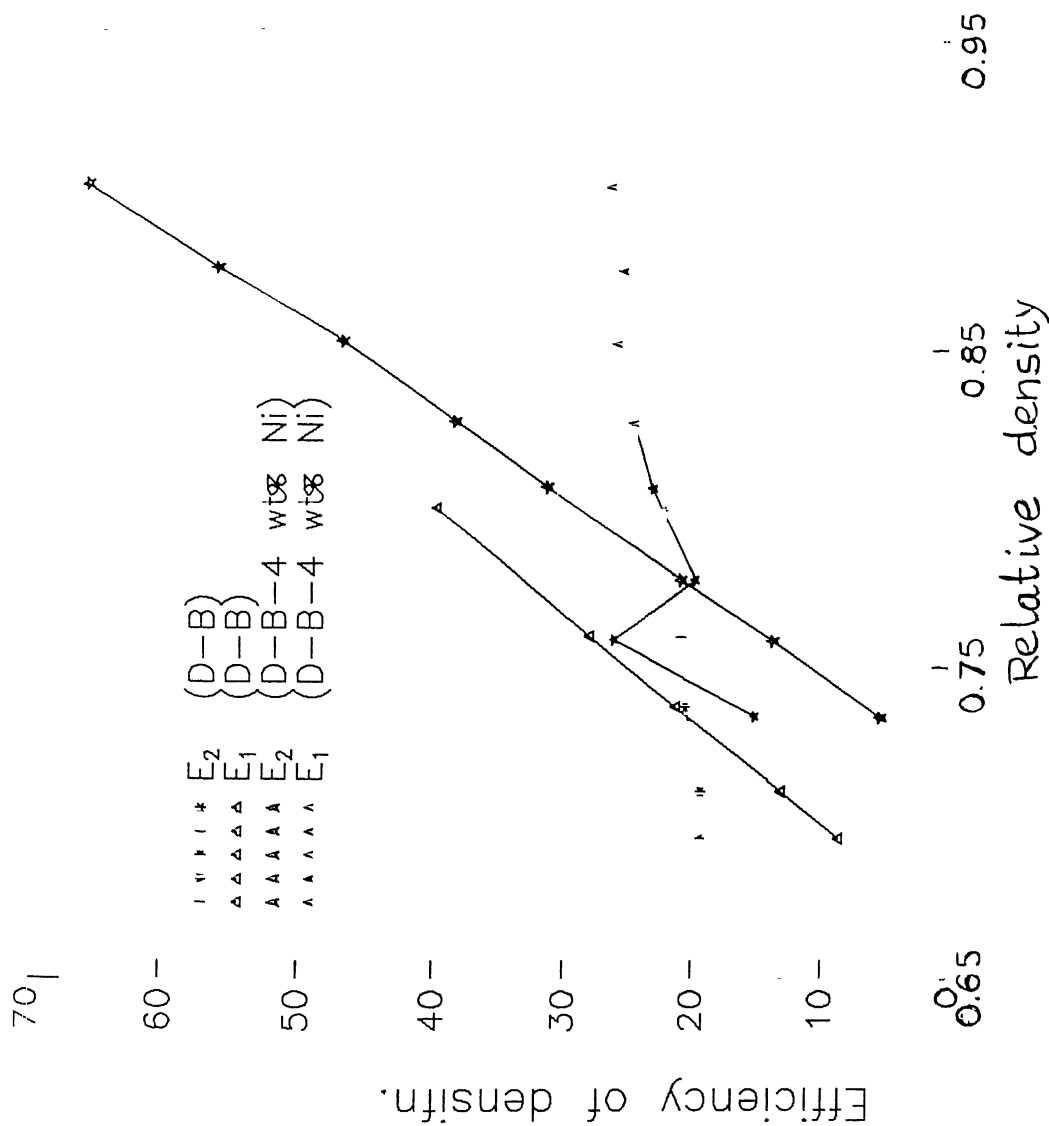
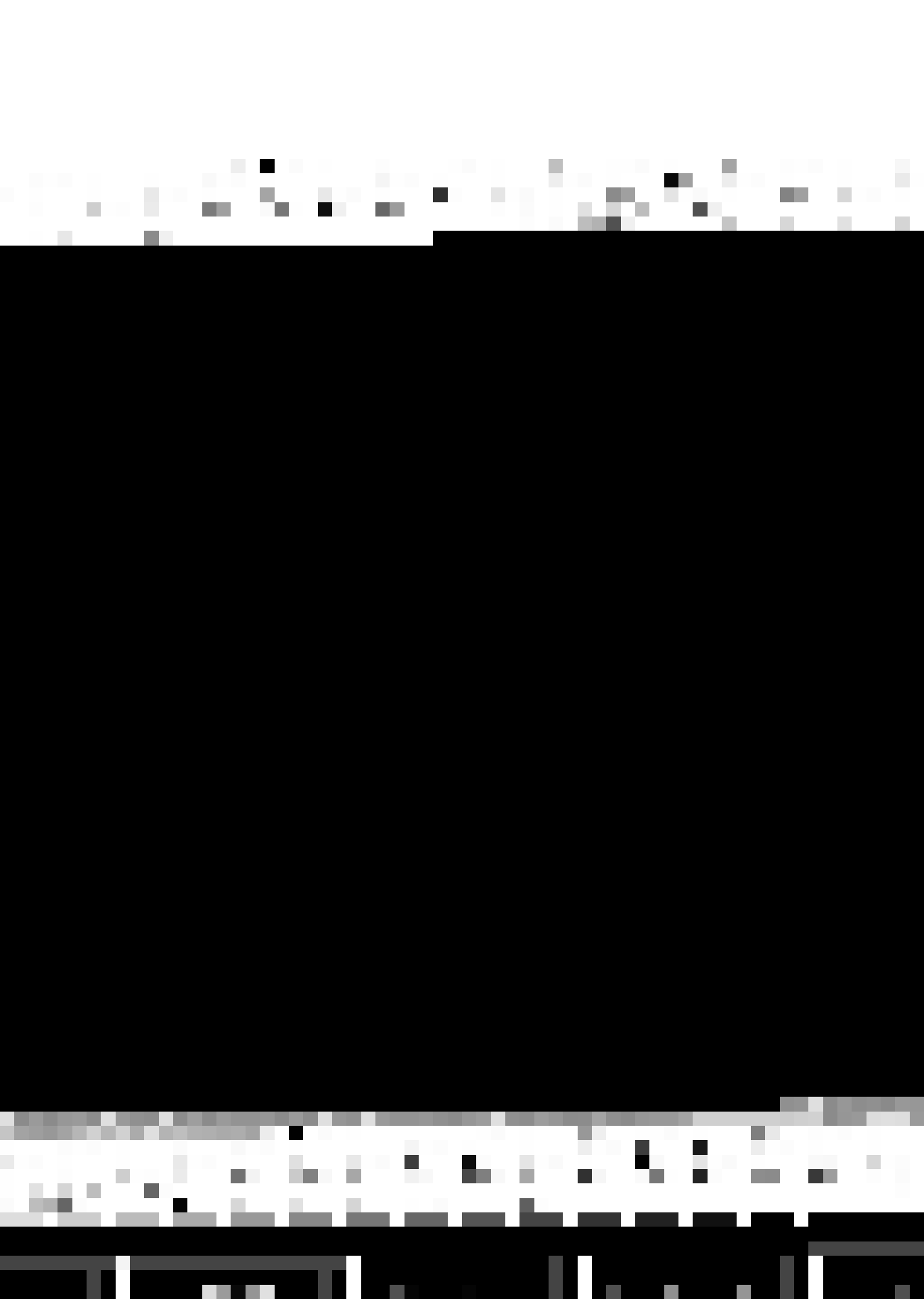


Fig 4.11 Efficiency of densification with respect to relative density



diamond-metal composite material. An absence of high density will make the product unsuitable for most of the diamond impregnated products. The lack of high density or the presence of porosity will cause two major drawbacks in a bond: low mechanical strength and low diamond retention capacity. High mechanical strength is necessary to avoid crumbling of product during use. A high porosity (or low density) will invariably decrease the surface area of the diamond grits in contact with the bond. As a result, a diamond grit can be detached from the matrix very easily.

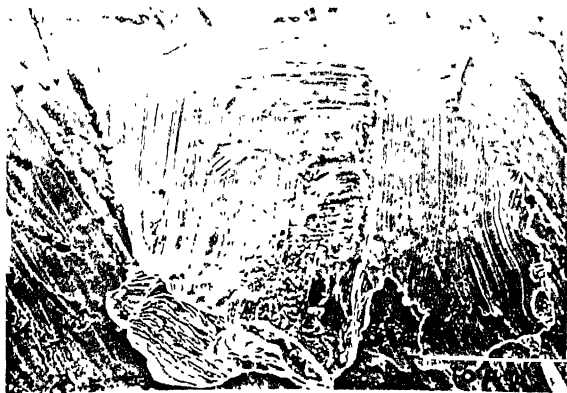
With the small size of the samples (0.5 inch dia), the amount of total thickness reduction by hot rolling that could be given was not greater than 60% for D-B composite pellets and 70% for D-B-4 wt% Ni composite pellet. Increased thickness deformation was restricted due to edge cracking which could not be ground off as it extended to the center of the samples. Increased deformation and hence increased densification could be achieved with samples of large diameter (1.0 inch). But pellets with larger dia could not be made due to the limitation in the hot press. With die of 1 inch, temperature could not be achieved more than 500°C, resulting in the samples of low strength. Another limiting factor in the hot press was the amount of pressure that could be applied, which was just 0.4 ton/inch<sup>2</sup>. Increased densification could be achieved with a hot press which has a provision of applying higher pressure.

#### 4.1.2 Microstructural Feature of D-B and D-B-4 wt% Ni Composite Material

SEM photograph of Nickel, bronze, diamond powders are shown in Fig 4.12. To study the microstructural features, SEM photographs of hot pressed and hot rolled samples at various thickness reductions were considered. These are presented in Fig 4.13 and Fig 4.14. It is observed that for D-B and D-B-4 wt% Ni composite material, deformation is



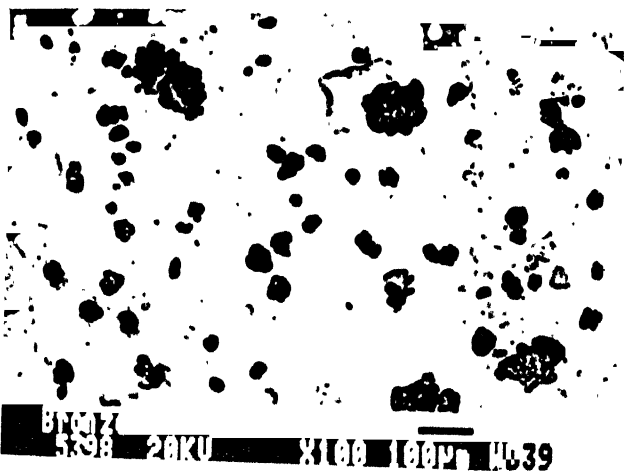




(a) Titanium (3000X)



(b) Nickel (3000 X)

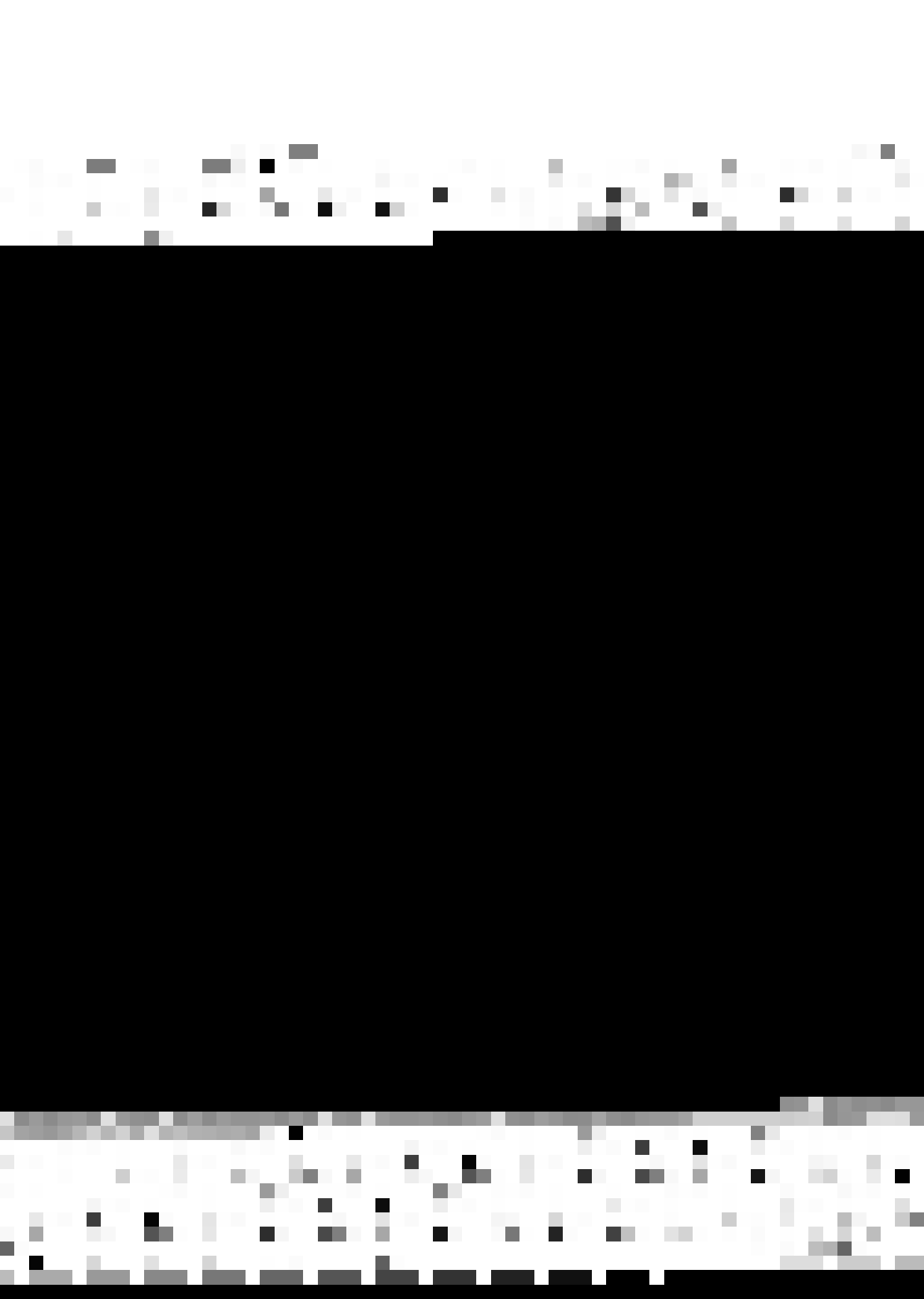


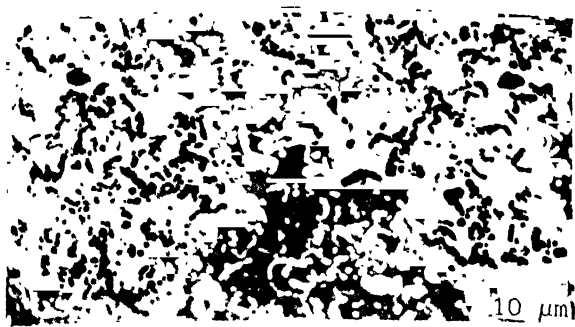
(c) Bronze



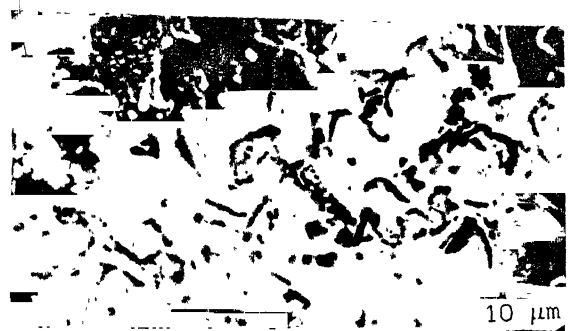
(d) Diamond

Fig 4.12 SEM of Ti, Ni, Diamond and Bronze powders

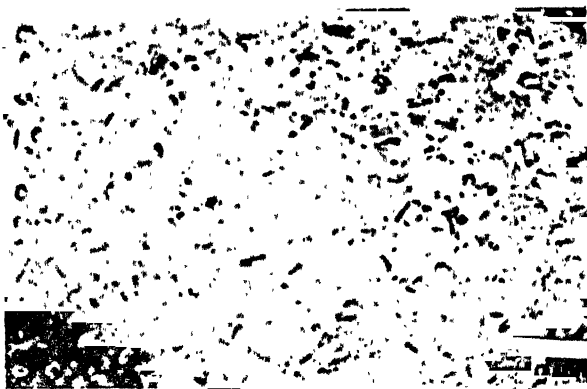




(a) Hot pressed (1000 X)



(b) 15% thickness reduction (500 X)



(c) 35% thickness reduction (1500 X)



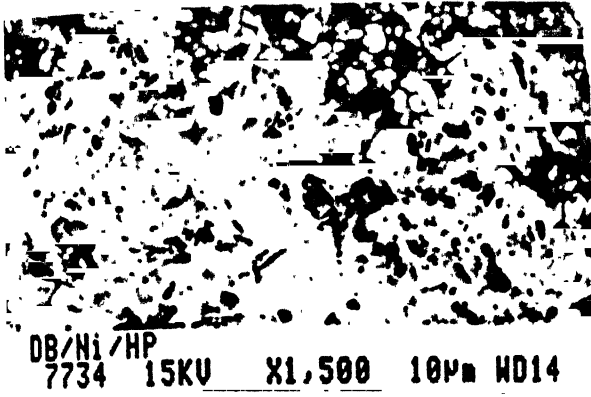
(d) 45% thickness reduction (1000 X)



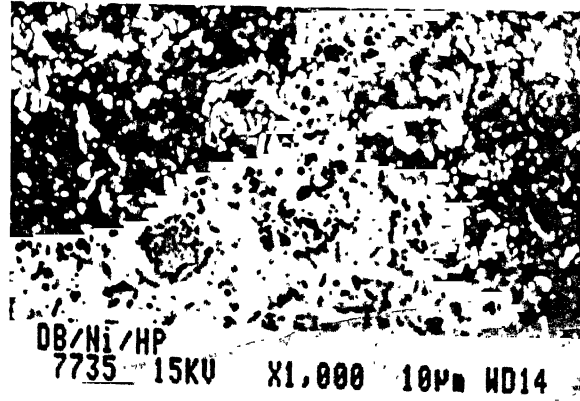
(e) 60% thickness reduction (1000 X)

Fig 4.13 SEM of hot rolled D-B composite material at various thickness reductions

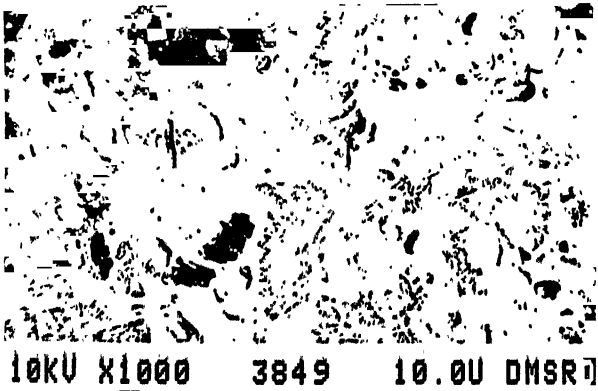




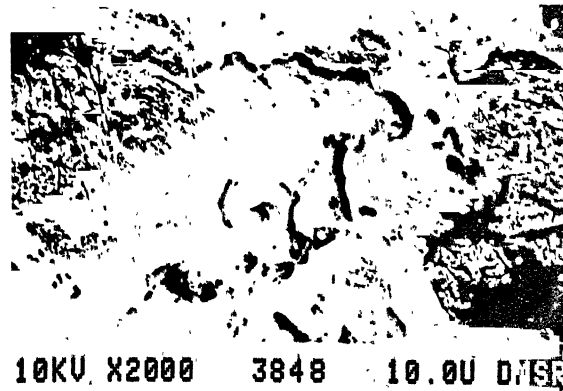
(a) Hot pressed-1



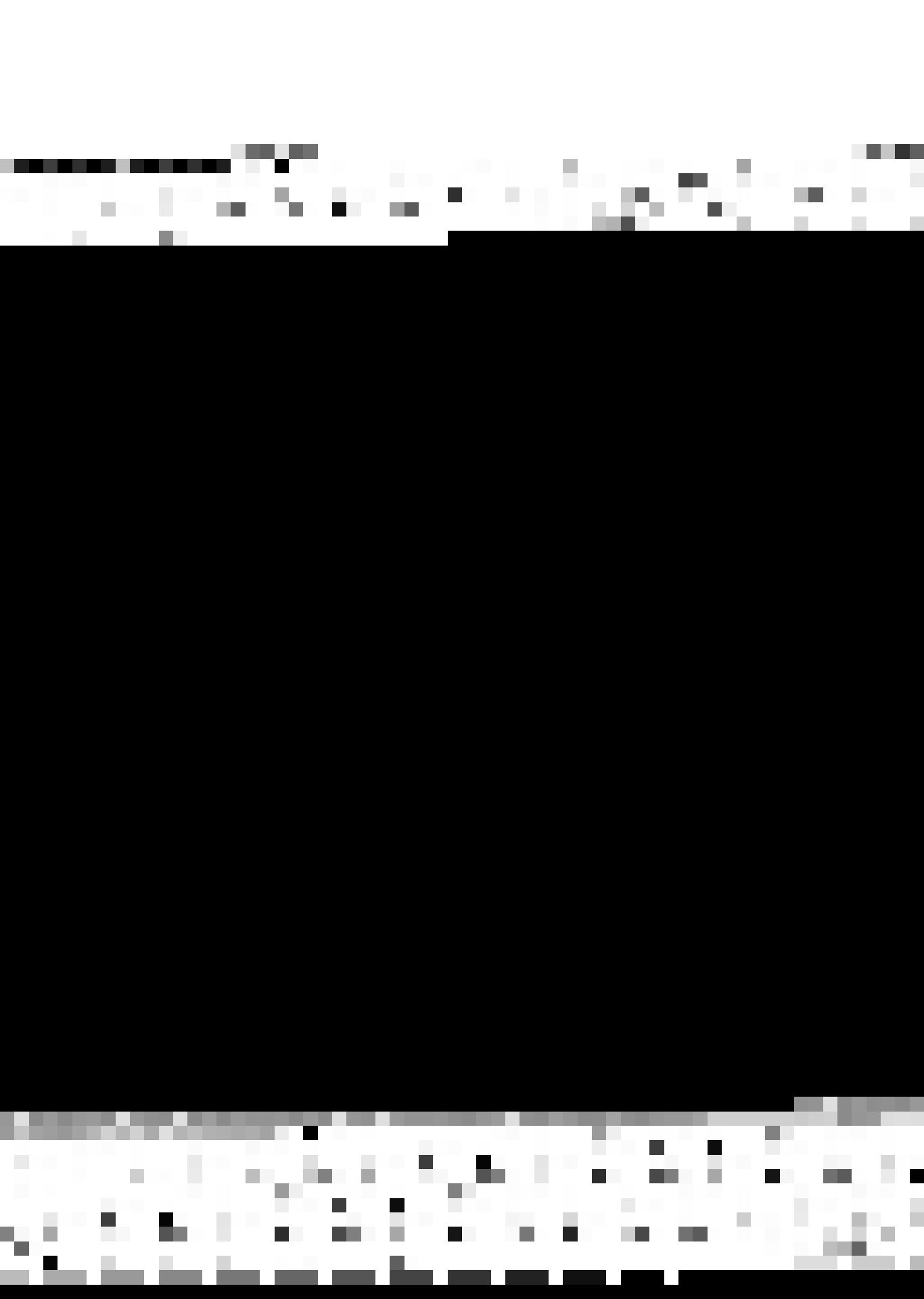
(b) Hot pressed-2



(c) 15% thickness reduction

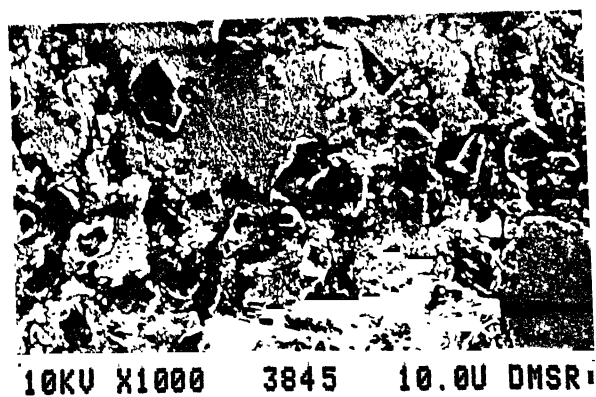


(d) 30% thickness reduction

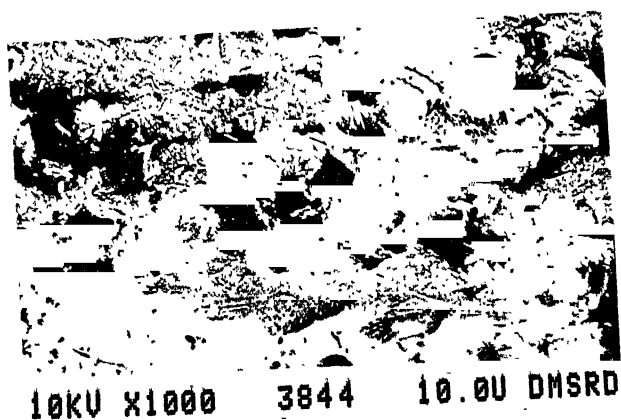




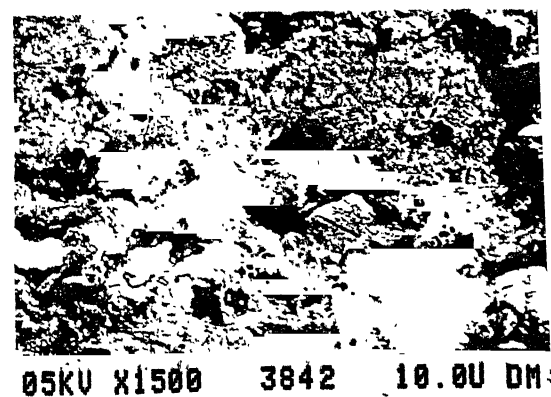
(e) 38% thickness reduction



(f) 51% thickness reduction

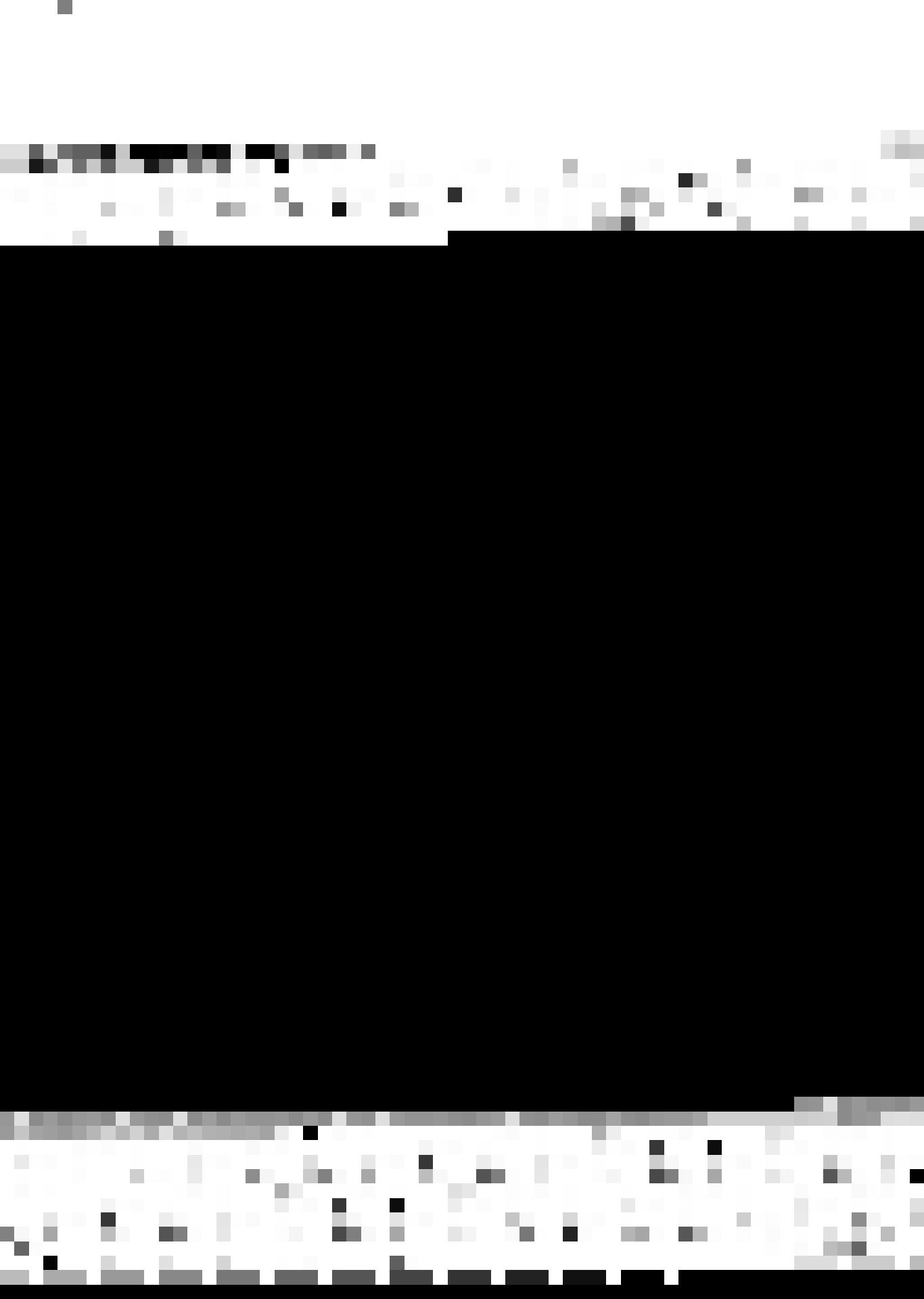


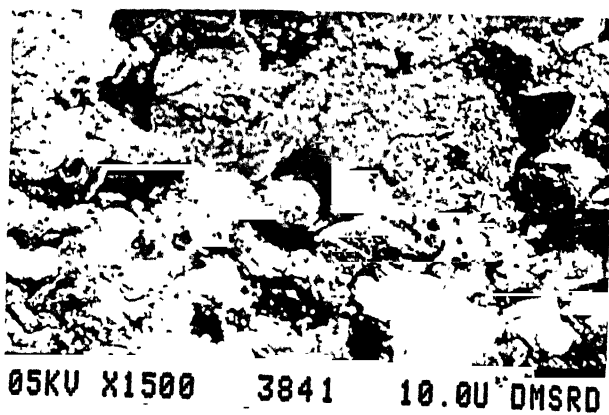
(g) 62% thickness reduction



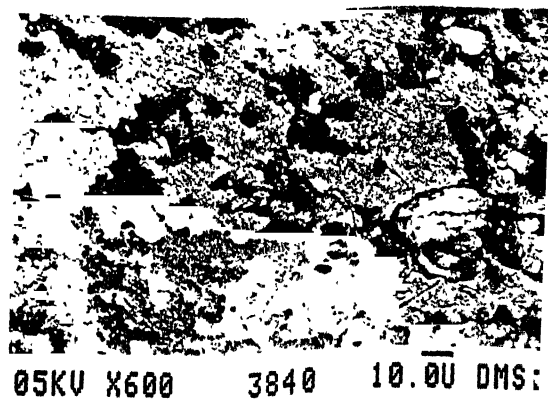
(h) 70% thickness reduction-1



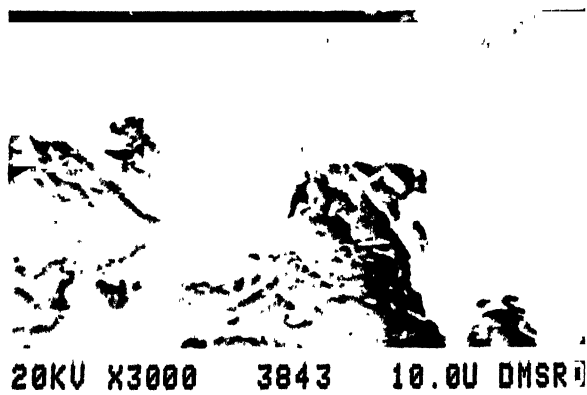




(i) 70% thickness reduction-2

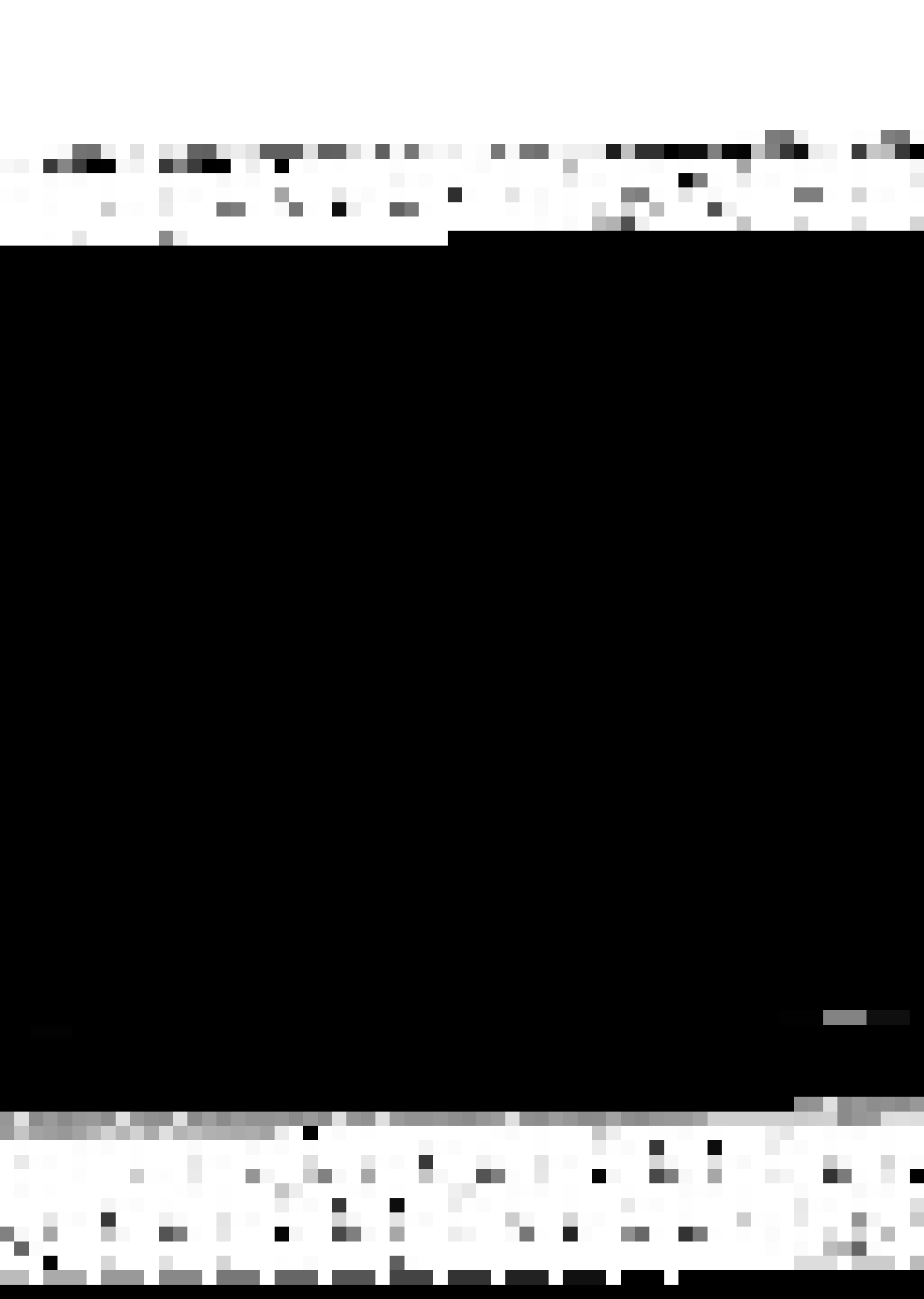


(j) 70% thickness reduction-3



(k) Diamond particle held tightly by matrix  
at 70% thickness reduction

Fig 4.14 SEM of hot rolled D-B-4 wt% Ni composite material at various thickness reductions



substantially confined to the bronze matrix. Diamond particles are mostly undeformed. The strain is concentrated only in the soft bronze matrix, leaving the hard diamond particles essentially undeformed.

Comparison of the SEM photographs at 60% total thickness reduction of D-B composite and at 70% total thickness reduction of D-B-4 wt% Ni reveals that the matrix for D-B-4 wt% Ni is more continuous, ie., better joining with the individual particles. Pores and cracks are fewer which implies that densification was better, matrix is stronger and the diamond grits are firmly embedded in the matrix. Diamond particles were well distributed in the bronze matrix and many diamond grains appeared to have formed into clusters. The interface between diamond and matrix for D-B composite material shows occurrence of cracks and there is a poorer retention of diamond particles in the matrix bond. In Fig 4.14 (No.3843), a single diamond particle was focused and it shows the way it is embedded in the matrix.

#### **4.1.3 Microhardness of D-B and D-B-4 wt% Ni Composite material**

Hardness is an very important control parameter. If the composition deviates substantially, the densification is incomplete, or the high temperature processing is faulty, the achieved hardness will not fall within the specified range. A bond composition properly densified during high temperature operations (fixed time, temperature and pressure cycles) will acquire a narrow hardness range.

Microhardness of the matrix of D-B and D-B-4 wt% Ni were measured in the "as hot pressed" and "hot pressed and hot rolled" conditions. These are summarised in Table 4.6 and Table 4.7. The relationship between the microhardness and the % hot rolling deformations is shown in Fig 4.16 and Fig 4.17. It can be seen that the microhardness increased with thickness





Fig 4.15 Photograph of D-B composite strips after hot rolling and D-B-Ti composite pellets after hot pressing.

- (a) D-B composite strip    (b) D-B-4 wt% Ni composite strip  
(c) Hot pressed (D-B-10 wt% Ti) composite pellet

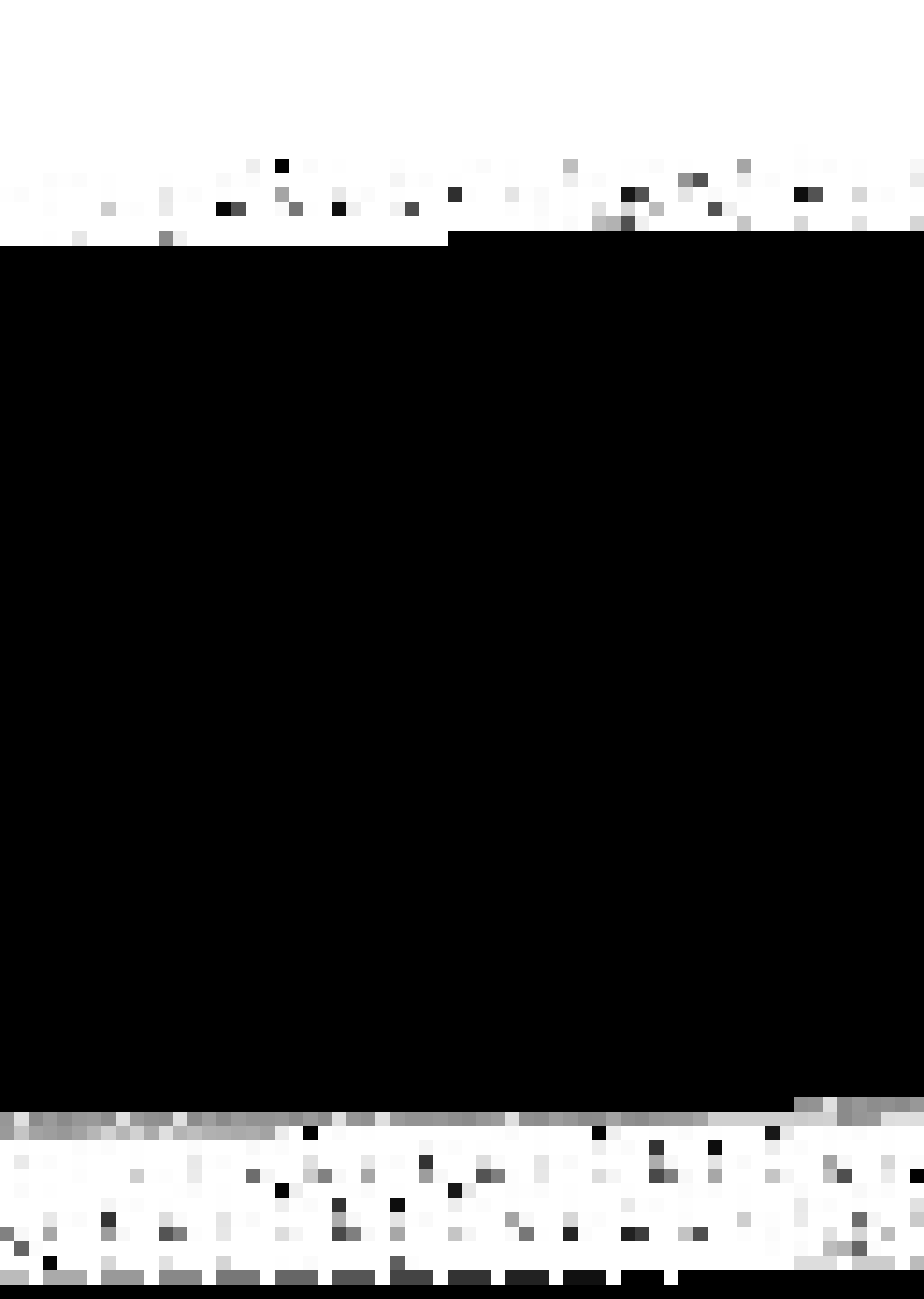


Table 4.6 Typical microhardness values for D-B composite strip at various thickness reduction.

Sample	% Total Deformaion	Microhardness (Hv)
H.P.	-	196
Pass-1	10	207
Pass-2	15	225
Pass-3	30	253
Pass-4	38	272
Pass-5	44	294
Pass-6	51	318
Pass-7	62	340
Pass-8	70	368

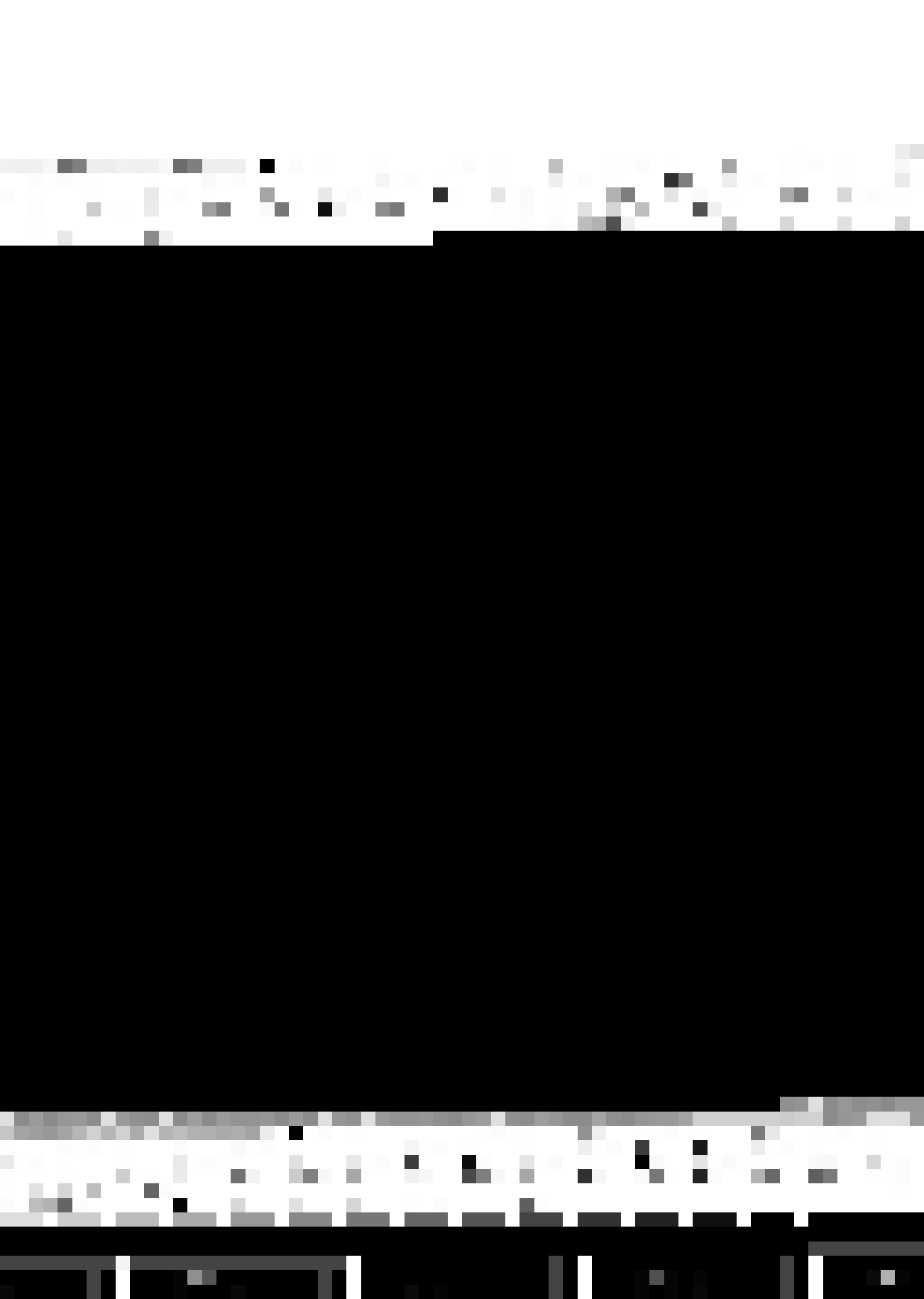
\* Load : 50 gm

Table 4.7 Typical microhardness values of D-B with 4 wt% Ni composite strip at various thickness reductions.

Sample	% Total Deformation	Microhardness (Hv)
H.P.	-	152
Pass-1	15	178
Pass-2	23	190
Pass-3	35	202
Pass-4	45	241
Pass-5	60	285

\* Load : 50 gm





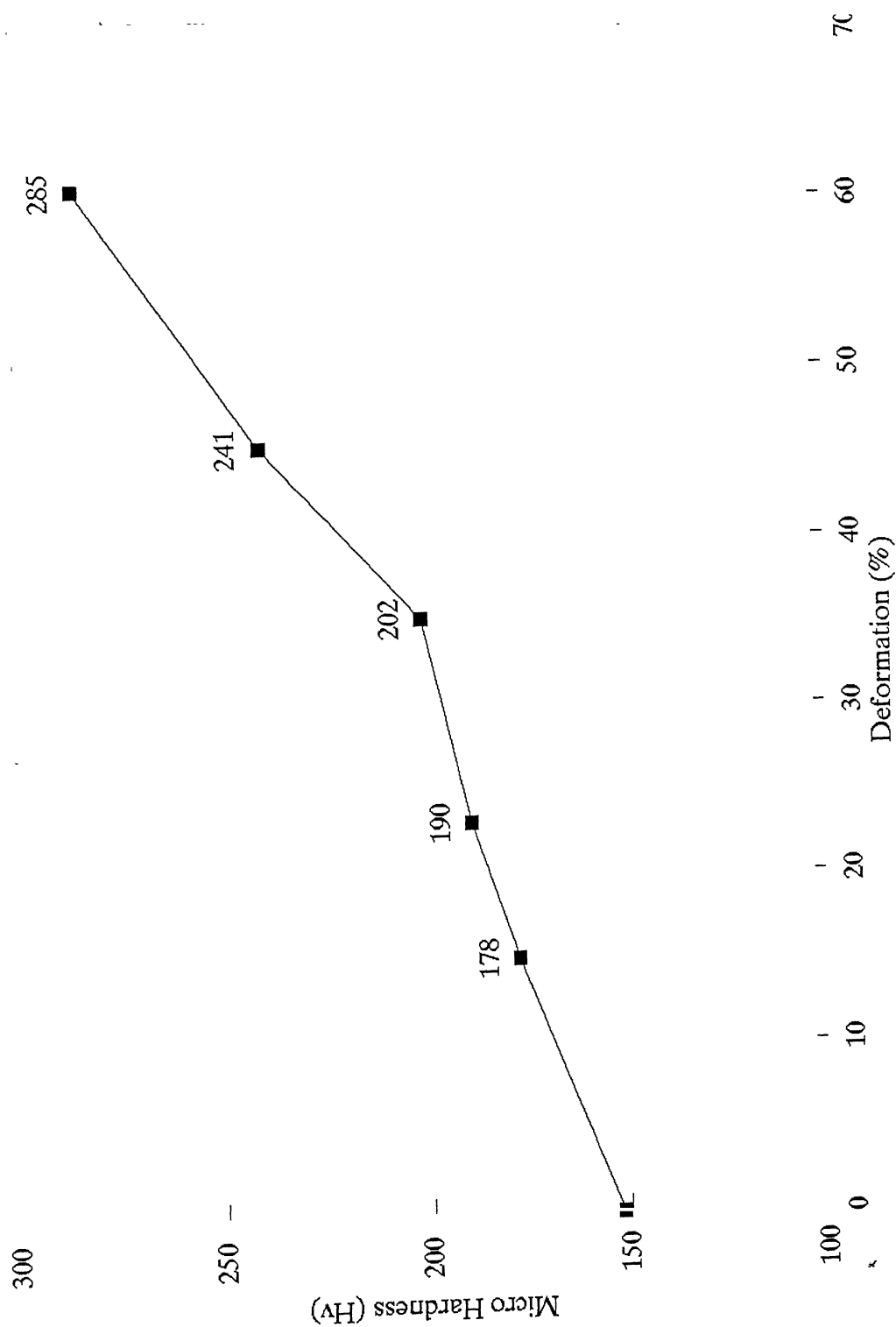
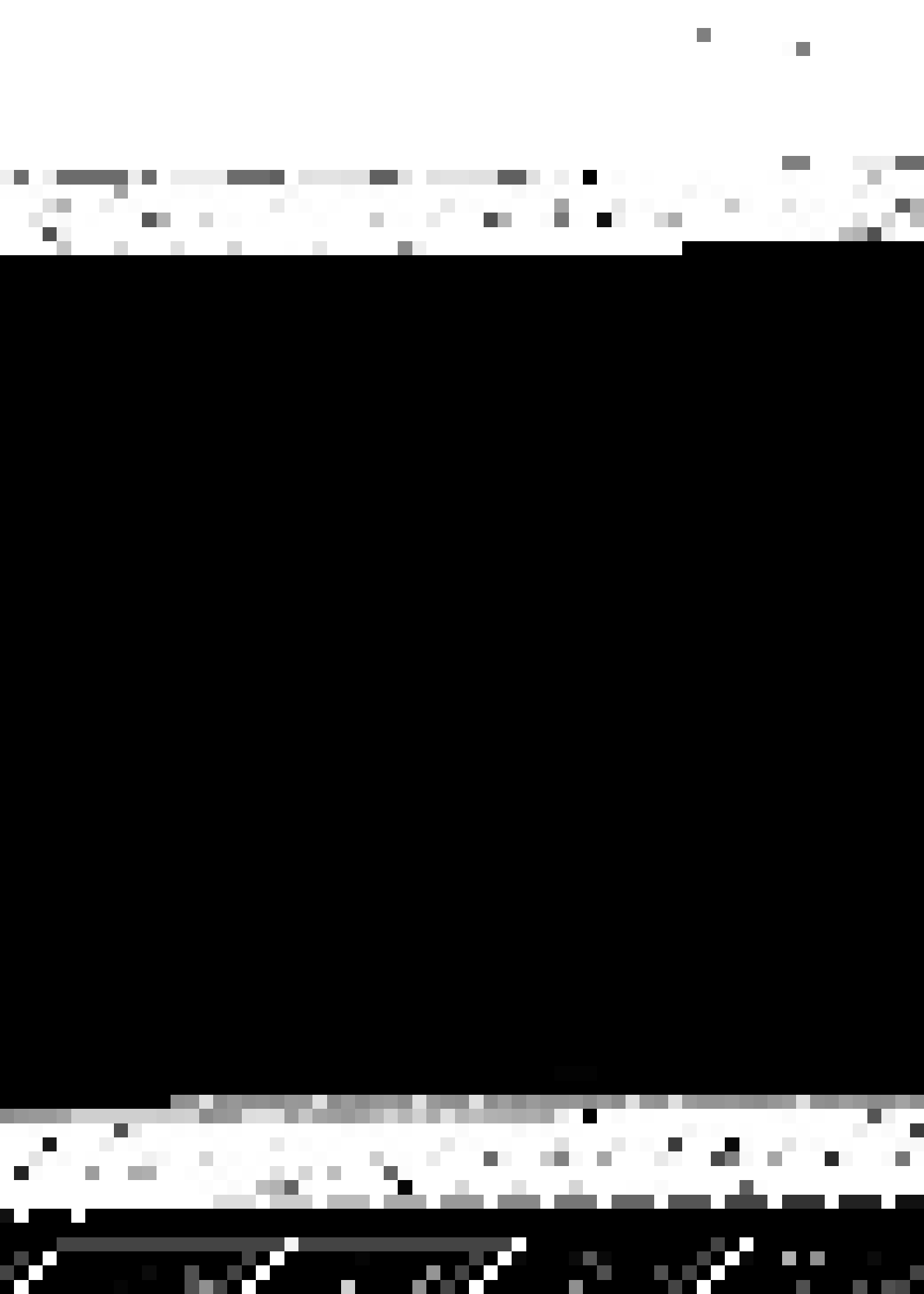


Fig 4.16 Effect of hot rolling deformation on the microhardness D-B composite material



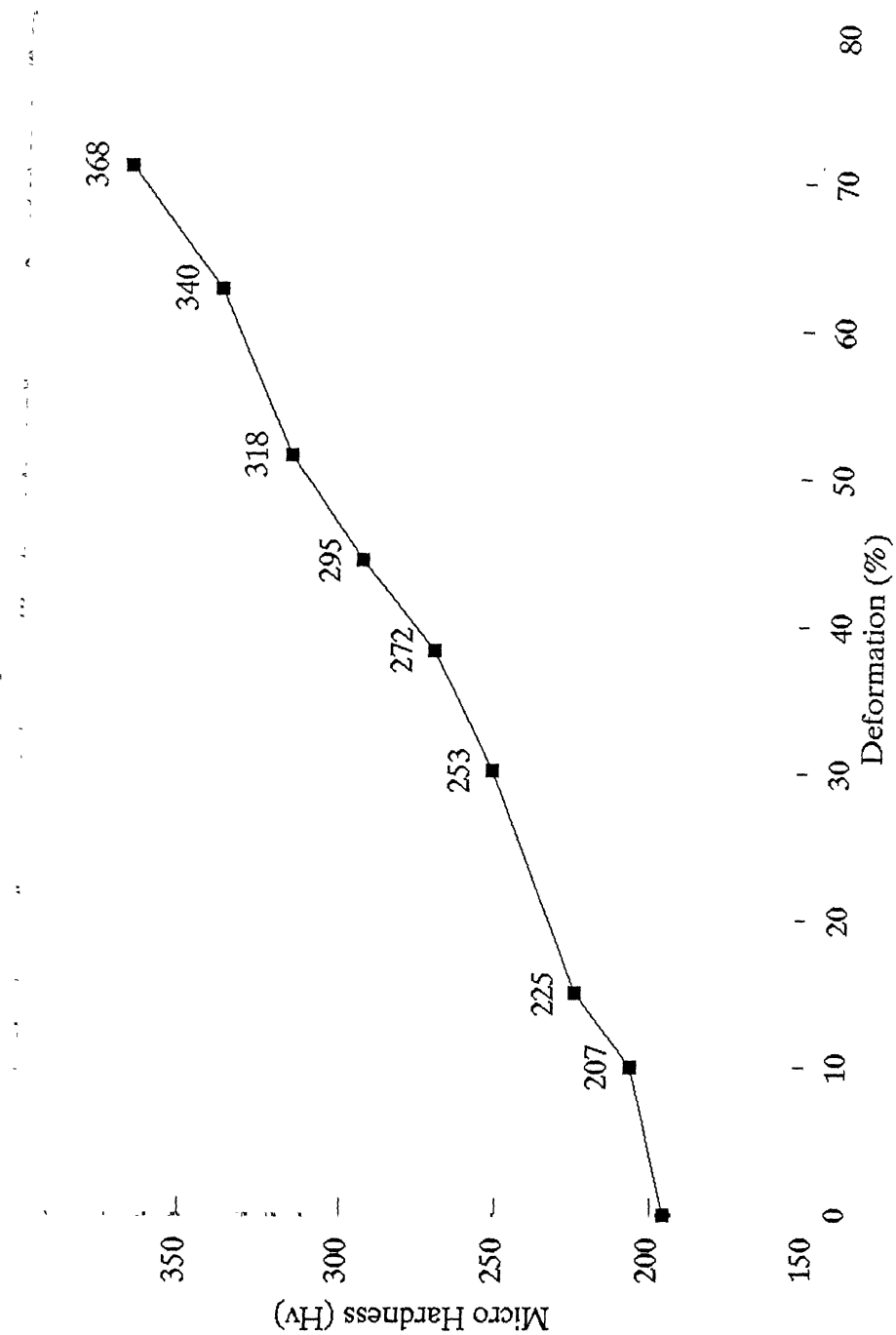
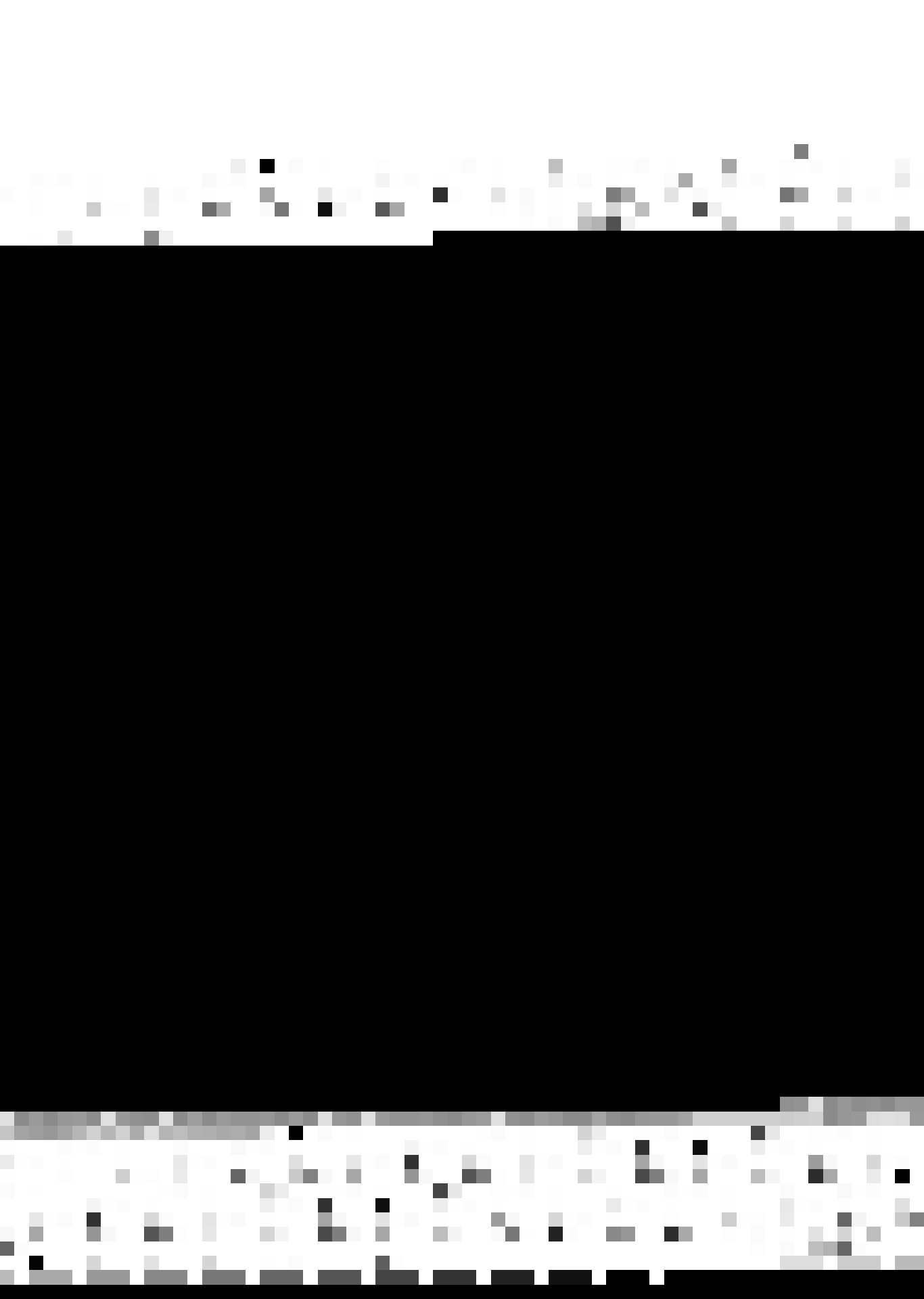


Fig 4.17 Effect of hot rolling deformation on the microhardness D-B-4 wt% Ni composite material



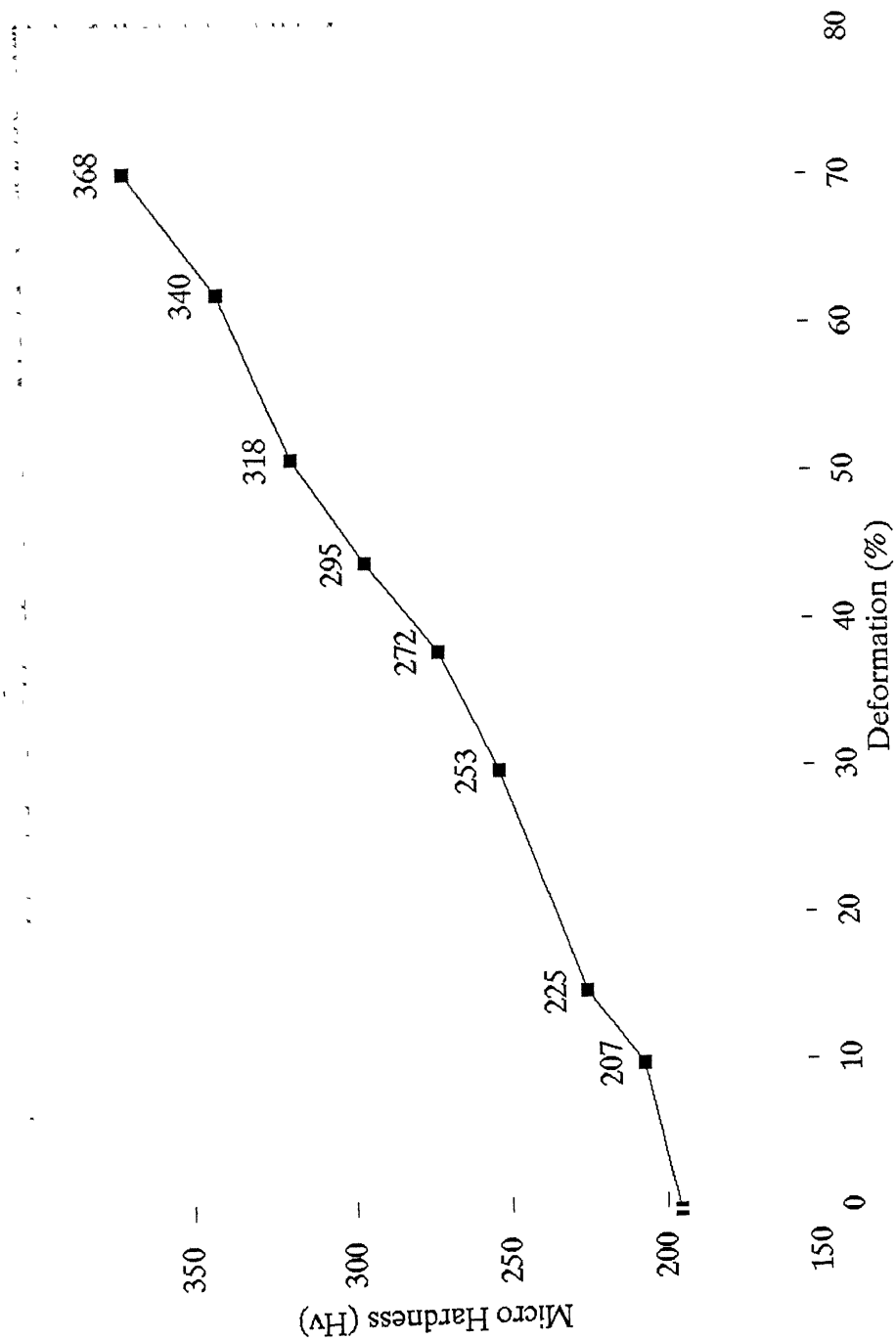


Fig 4.17 Effect of hot rolling deformation on the microhardness D-B-4 wt%  
Ni composite material



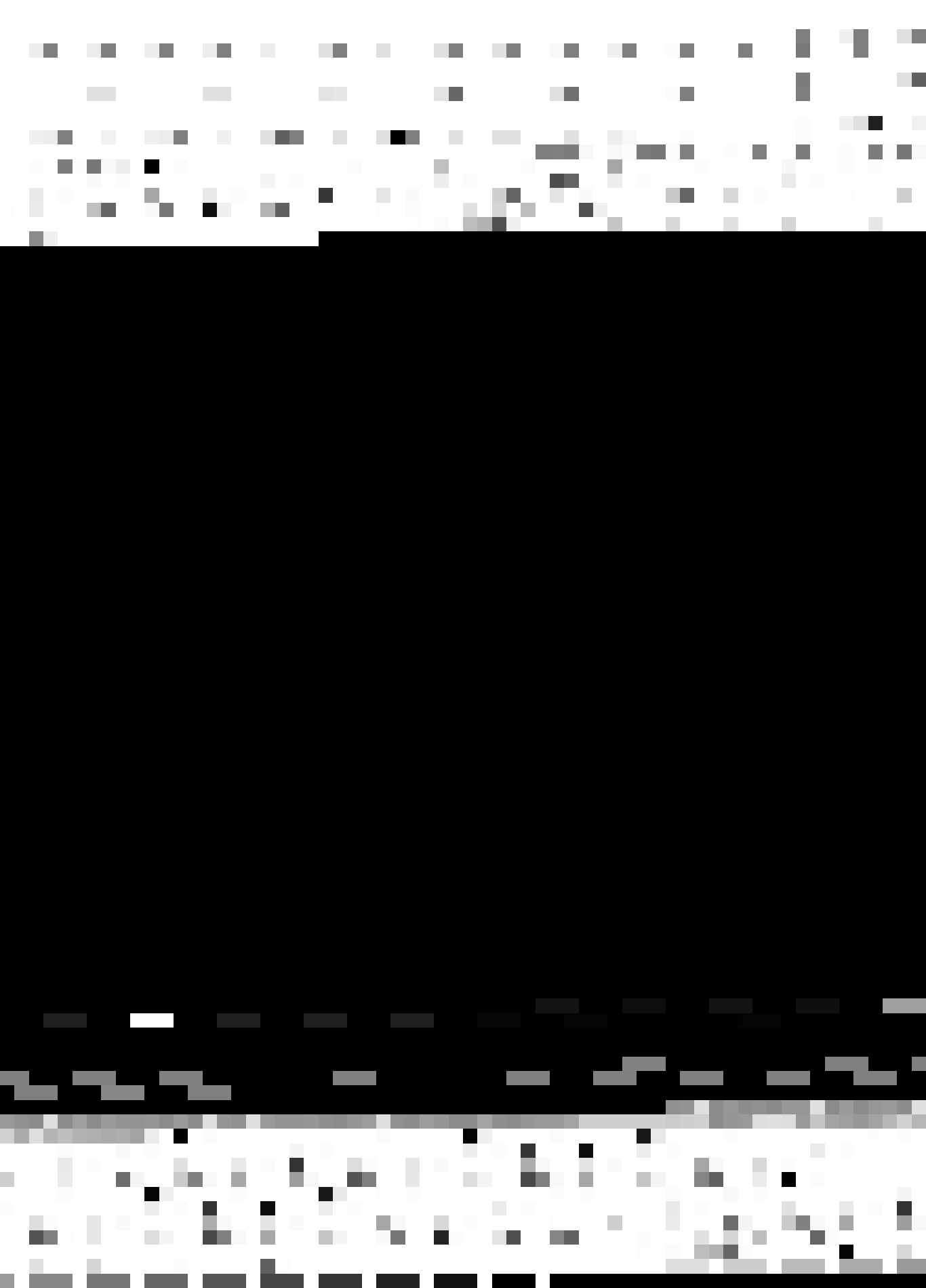
reduction for both D-B and D-B-4 wt% Ni composite material. But the increase can be more prominently observed in case of D-B-4 wt% Ni composites. The increase in the hardness can be attributed due to the increase in density with the thickness reduction. Another factor contributing to this effect may be that some strain hardening has been induced in the bronze grains during rolling operation. When the samples are drawn out from the furnace, the temperature of the specimen is continuously decreasing. When the sample comes in contact with the cold rolls of the rolling mill, there is a chilling effect. As a result of it, there is a possibility that some work hardening has been induced in the sample. This aspect needs more investigation for clear understanding.

As discussed earlier efficiency of densification of D-B- 4 wt% Ni is better, hence the increase in microhardness value is higher as compared to D-B composite material. Measurement of hardness of diamond was not carried out as the actual measurement is very difficult and even if it is carried out will give erroneous picture a different faces of diamond crystal exposed to the indenter will give different hardness value.

#### 4.1.4 X-RAY Analysis

X-RAY analysis of the rolled samples of D-B and D-B-4 wt% Ni composite material was carried out. It was found that the amount of graphite formation was more in case of samples with Ni. This was due to the tendency of diamond to convert into graphite at high temperature in contact with the transition metals like Ni. Therefore the amount of Ni which is added to enhance the strength of the matrix, should be carefully controlled. In other words, total integrity of the diamond must be maintained in order to take advantage of the unique properties of diamond. If the amount of the ingredients which aid graphitization is not minimized,





a portion of the diamond content will be converted into graphite and the life of the product will be shortened. X-RAY data and the X-RAY diffraction pattern is presented in Table 4.8 and Fig 4.18.

## 4.2 DIAMOND-BRONZE-Ti COMPOSITE MATERIAL

Diamond-Bronze-Ti (D-B-Ti) composite with varying Ti concentrations were prepared by hot pressing. Hot pressing was carried out at a temperature of  $830^{\circ}\text{C}$  at a pressure of  $0.4 \text{ ton/inch}^2$ , and was held at this pressure for 60 min. The hot pressed samples were additionally sintered at  $800^{\circ}\text{C}$  in Ar atmosphere for 1 hr.

### 4.2.1 Densification Behaviour

Cu-Sn-Ti alloy, wets and bonds well to diamonds at temperature as low as  $900^{\circ}\text{C}$ . There is enhancement of Ti activity by Sn and the resultant production of metal rich, more wettable, TiC reaction product layer at the alloy-carbon interfaces. The density of hot pressed pellets are summarised in Table 4.9. It could be seen that the density increases with the increase in the Ti content, the maximum value is shown by the samples with 15% Ti. There is a direct correlation between the amount of Ti and the percentage densification achieved. Highest value of % densification is obtained for the sample to which both 10% Ti and 4% Ni were added. The density of the hot pressed samples are presented in the form of histogram in Fig 4.23. Ti powder was obtained by filing round Ti bar and the particles were coarse and hence packing was not uniform during pressure sintering and there was a problem to attain very high density ( $>96\%$ ) even after hot pressing followed by sintering in Ar atmosphere. Finer Ti particles, if used, will lead to better sintering of the composite and hence higher density can be achieved,

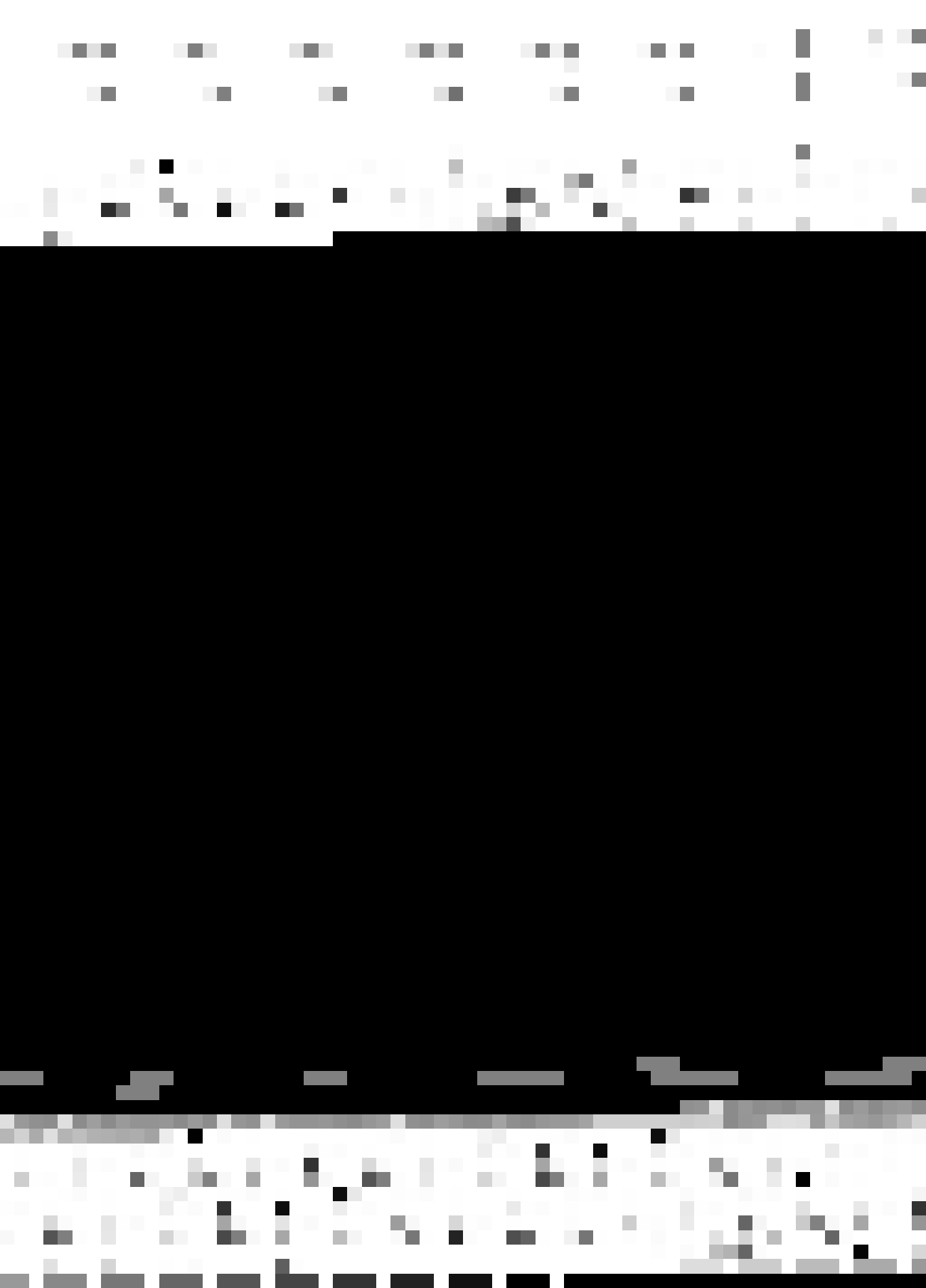


Table 4.8 Data for the X-RAY analysis

Sample	Phase	Observed peak position		Standard d	hkl
		2 $\theta$ deg	d Å°	Å°	
D-B (10 wt% Ti)	TiC	60.4	1.5308	1.5302	220
		72.2	1.3070	1.3047	311
		90.6	1.0840	1.0818	400
		105.5	0.9670	0.9677	420
		133.0	0.8390	0.8327	511
D-B	Graphite	26.8	3.34	3.348	003
		135.3	0.83	0.837	116
		26.7	3.3347	3.348	003
		50.5	1.8053	1.800	102
		90.2	1.0870	1.0880	201
D-B (4 wt% Ni)	Graphite	91.8	1.0722	1.0750	202
		95.2	1.0433	1.0450	203
		101.2	0.9960	0.9902	118
		136.5	0.8290	0.8259	119
		144.9	0.8070	0.8010	211
		160.1	0.7818	0.7895	214



a, D-B

Λ

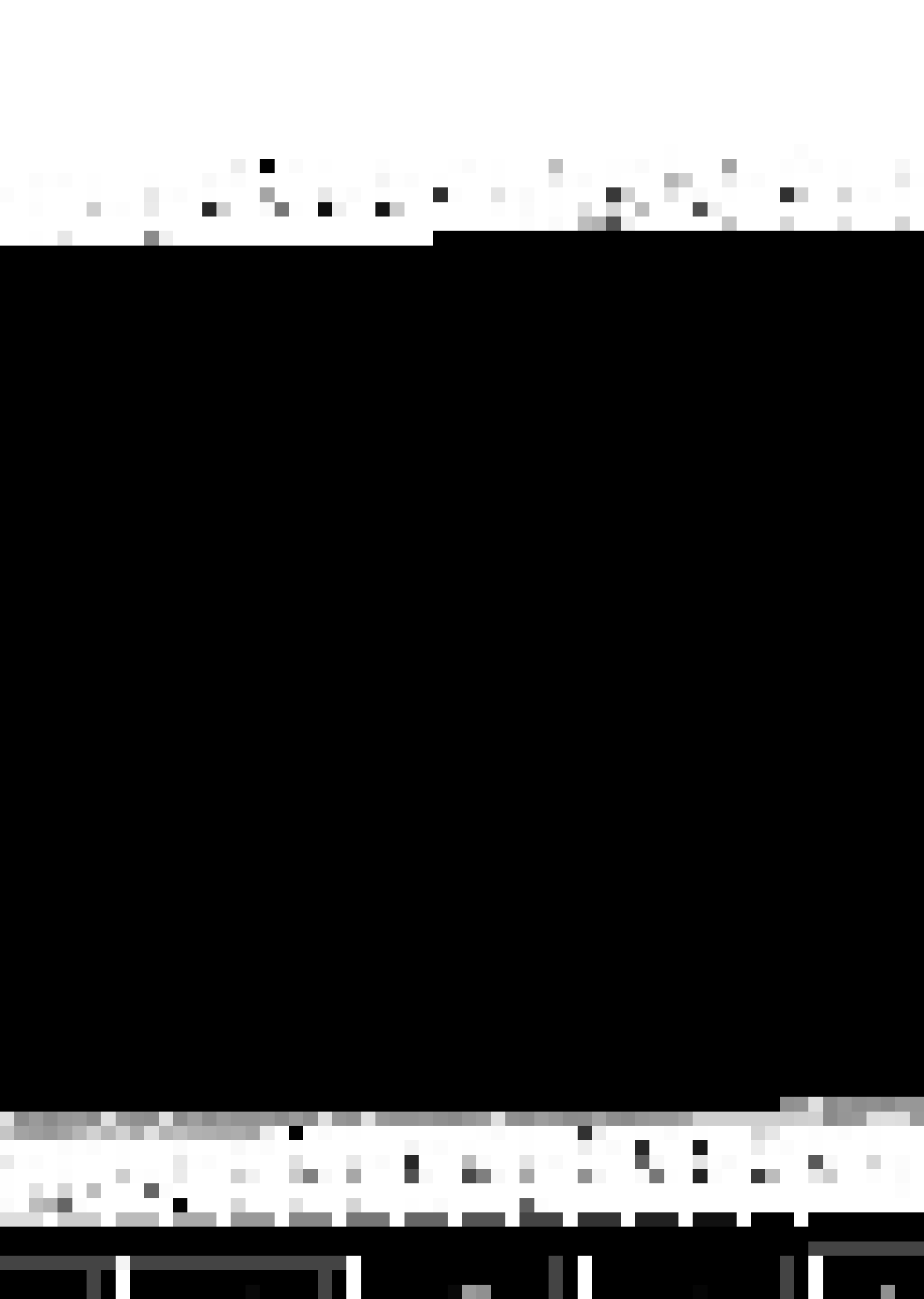
Graphite

Graphite

135.3

26.8

contd.,



b. D-B (4 wt% Ni)

Graphite

Graphite

Graphite

Graphite

Graphite

Graphite

Graphite

Graphite

Graphite

101.2

95.2

91.8

90.2

50.5

160.1

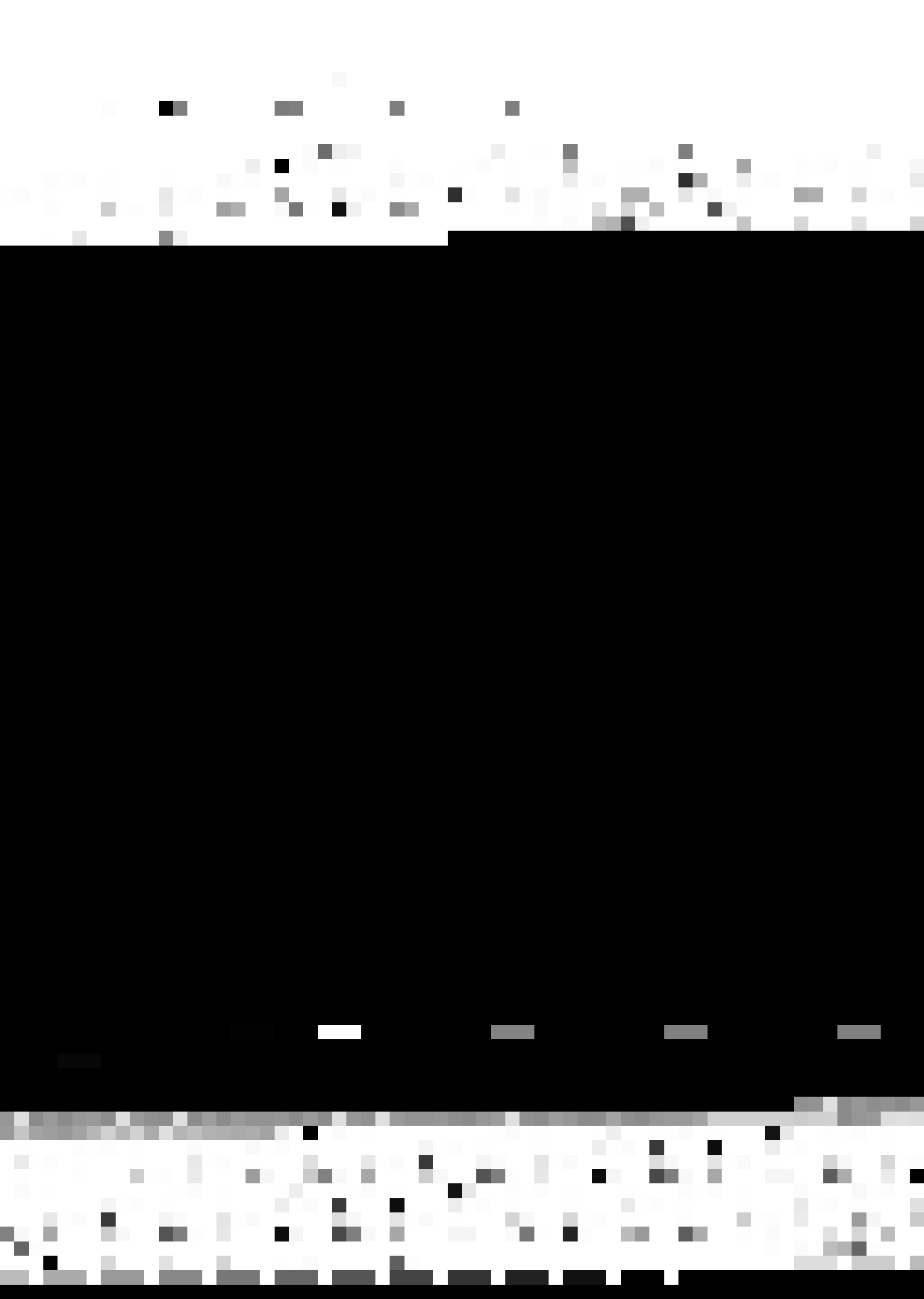
144.9

136.5

26.7

contd.,





C. D-B(10 wt% Ti)

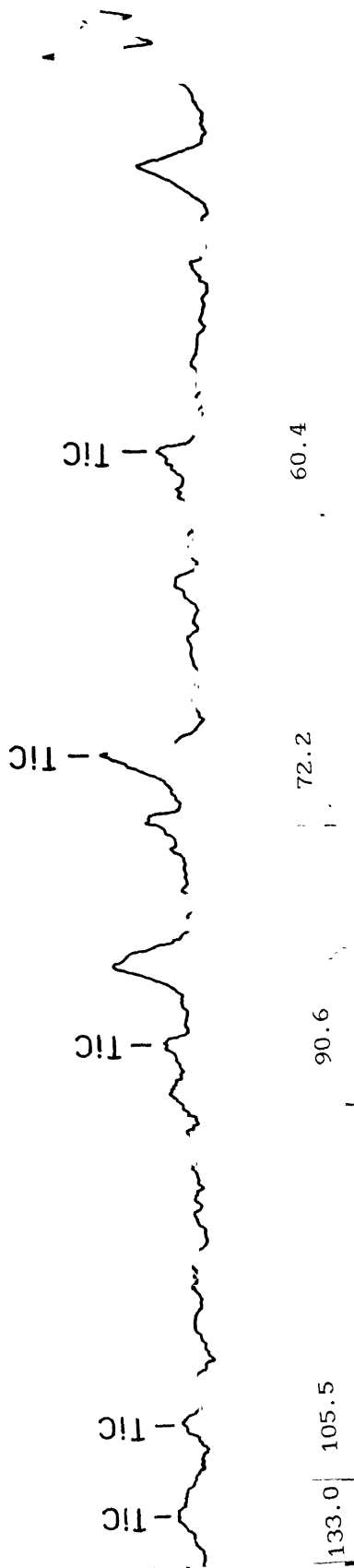


Fig 4.18 X-RAY diffraction pattern of (a) D-B (b) D-B-4 wt% Ni (c) D-B-10 wt% Ti

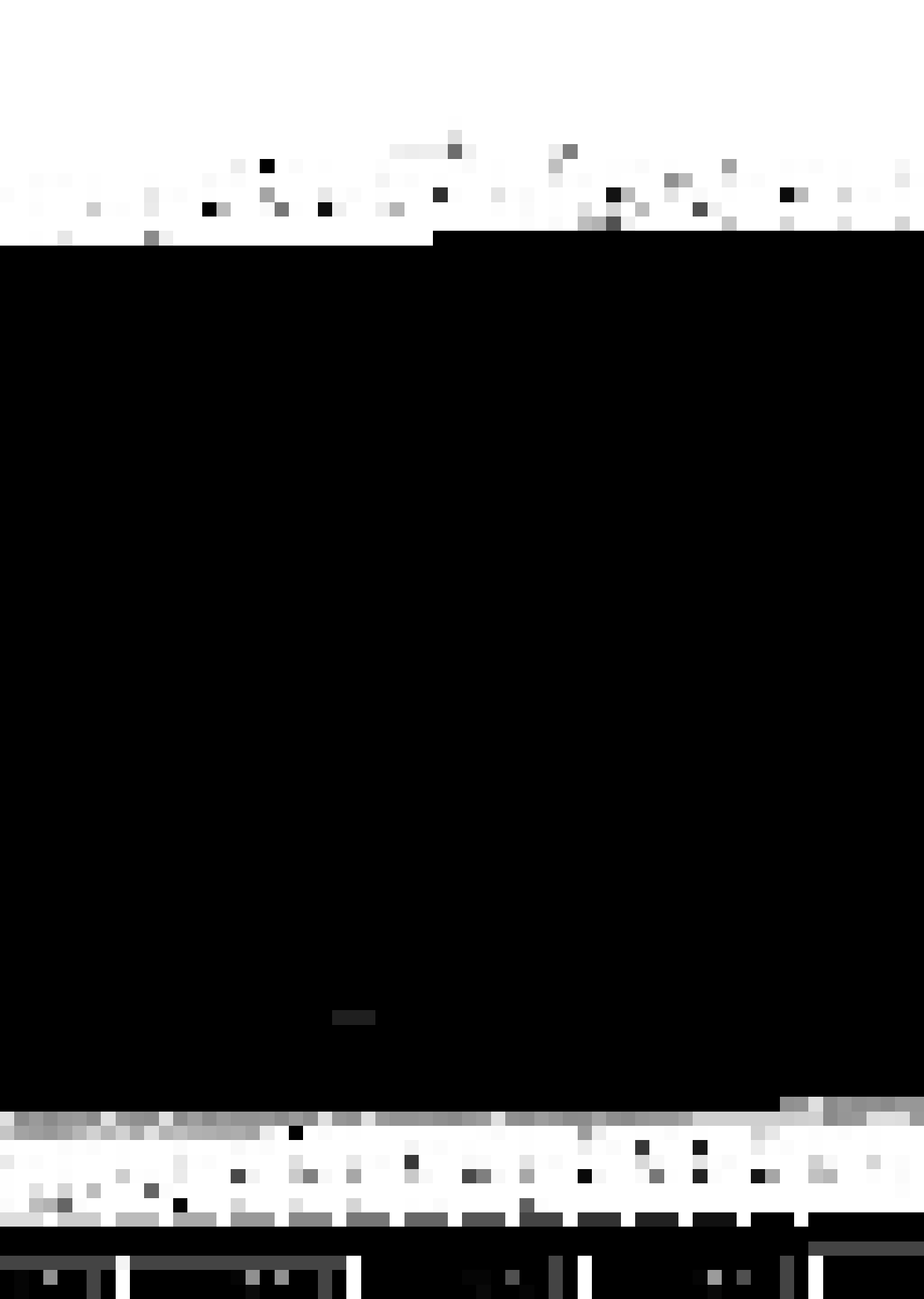


Table 4.9 Density of hot pressed D-B composite pellet with  
varying Ti and Ni contents.

Sample Composition (wt%)	Theoretical Density (g/cc)	Sintered Density (g/cc)	% rel densfn.
H.P. (DB + 5% Ti)	5.76	5.289	91.8
H.P. (DB + 10% Ti)	5.67	5.286	93.1
H.P. (DB + 15% Ti)	5.59	5.30	94.8
H.P. (DB + 10% Ti + 4% Ni)	5.75	5.49	95.6

**\* Hot pressing conditions:**

Temperature : 830°C

Pressure : 0.4 tons/inch<sup>2</sup>

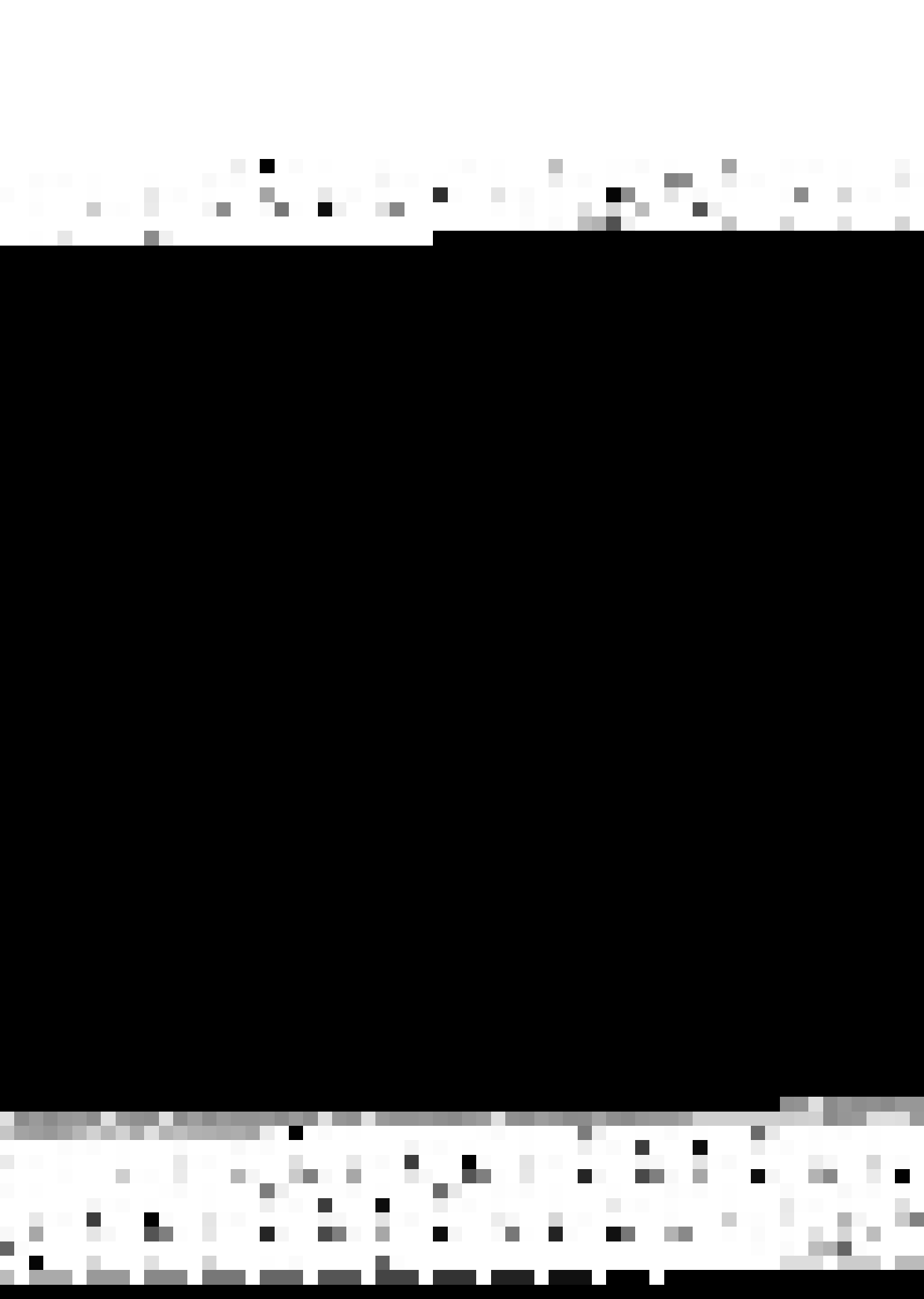
Holding time: 60 min

**Sintering conditions:**

Temperature : 800°C

Time : 60 min

Atmosphere : Argon



since fine Ti particles will provide a greater interfacial contact with the diamond surface. Ti is an active element easily oxidised, nitrified and hydrogenised. Therefore, the sintering of the samples should be carried out in Ar atmosphere or vacuum.

#### 4.2.2 Microstructural Features

The SEM photographs of the hot pressed D-B-10 wt% Ti, D-B-15 wt% Ti, D-B-10 wt% Ti-4 wt% Ni are shown in Fig 4.19. SEM photograph reveals that the matrix is continuous with diamond particles distributed uniformly in the matrix. Pores and cracks are very less and the diamond particle are held very tightly to the matrix.

#### 4.2.3 X-RAY Analysis

X-RAY analysis was done for D-B-10 wt% Ti composite pellet. X-RAY data are given in Table 4.8 and the diffraction pattern is shown in Fig 4.18. Formation of TiC is verified from the X-RAY analysis. The tendency of formation of TiC at the interface is due to the strong affinity for diamonds, enabling Ti atoms to infiltrate into the surface of the diamonds. Rest Ti atom exists in the alloy in the form of complex intermetallic compounds. The greater the distance from the interface, the smaller the quantity of TiC formed.

#### 4.2.4 Microhardness Measurement

Microhardness of the matrix measured for D-B-10 wt% Ti. The various states as observed by SEM, composition and the structure is summarised in Table 4.10. The compositions of various phases are measured by EDAX analysis. Typical microstructure for D-B-10 wt% Ti can be seen from Fig 4.19 (No.7733). Microhardness of TiC phase is the highest compared to the rest of the states of the matrix. In general, the hardness

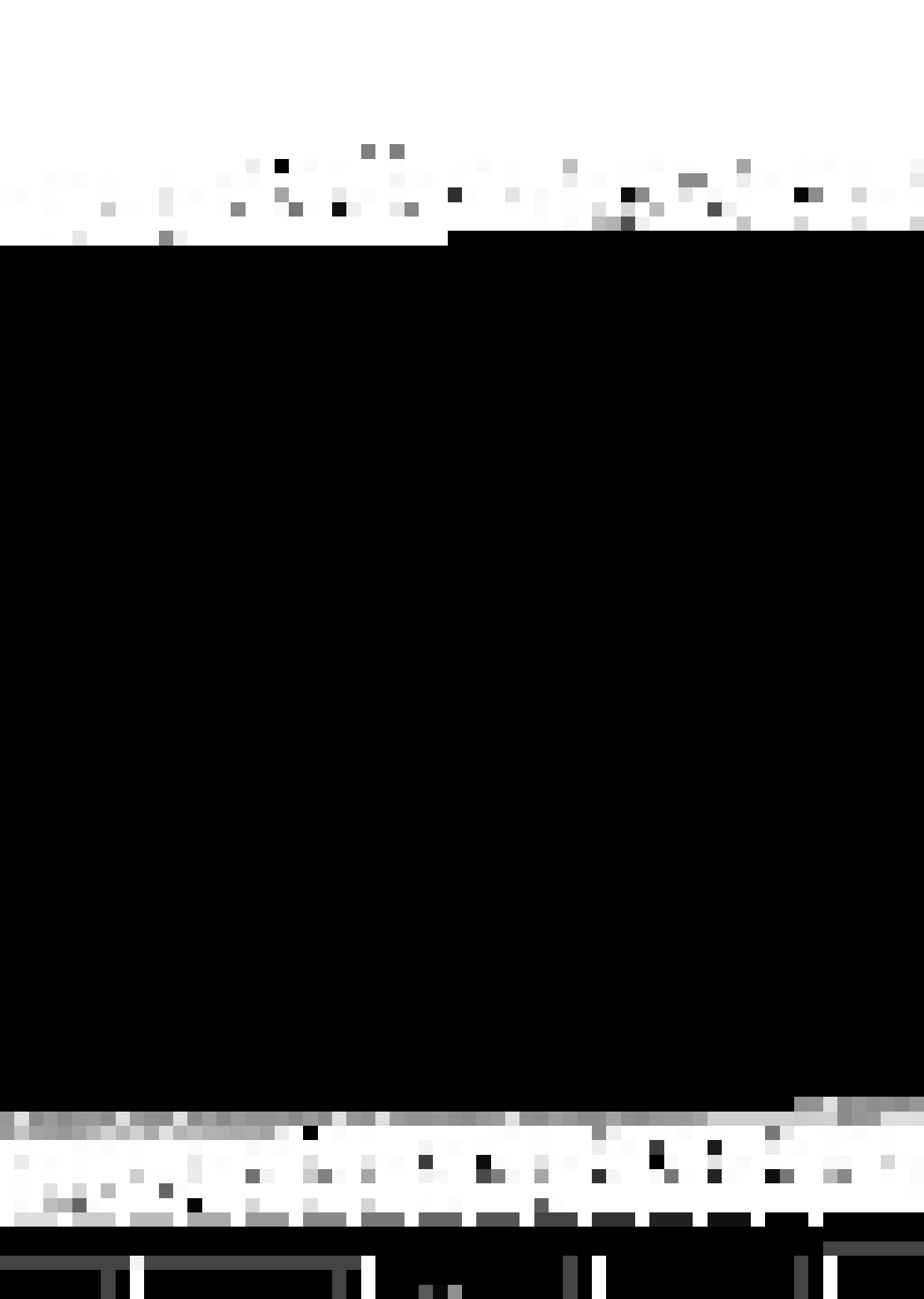


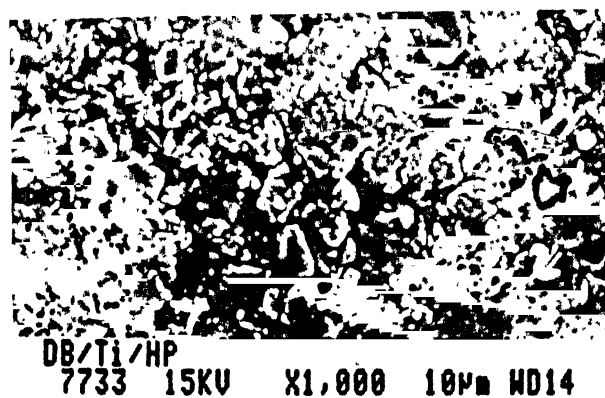
Table 4.10 Typical microhardness values of D-B with 10 wt% Ti composite pellet.

No.	States observed by SEM	Micro-hardness (Hv)	Composition	Structure
A	White layer formed on the Diamond-matrix interface	490	Ti-75% Cu-20% Sn-05%	TiC, sandwiched by 'Cu' alloy
B	White small block distributed on the Diamond-matrix interface	310	Ti-65-75% Cu-15-20% Sn-20-05%	TiC & complex intermetallic compound
C	Area away from D-B interface	185	Ti-30% Cu-60% Sn-10%	Complex intermetallic compound

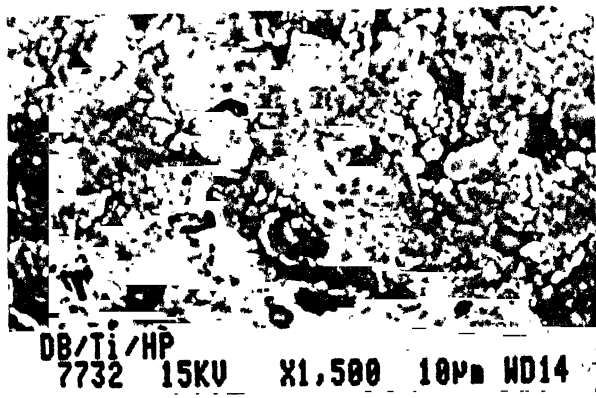
\* Load = 50 gm.



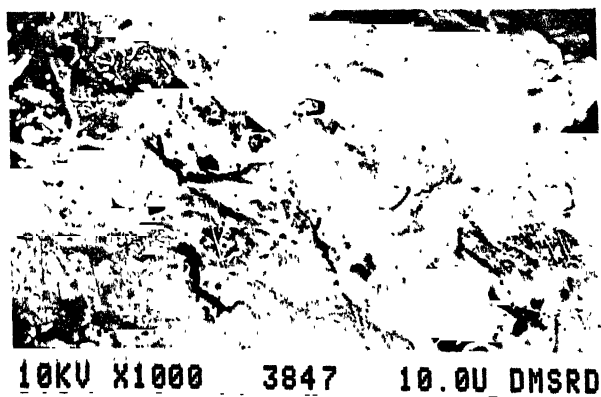




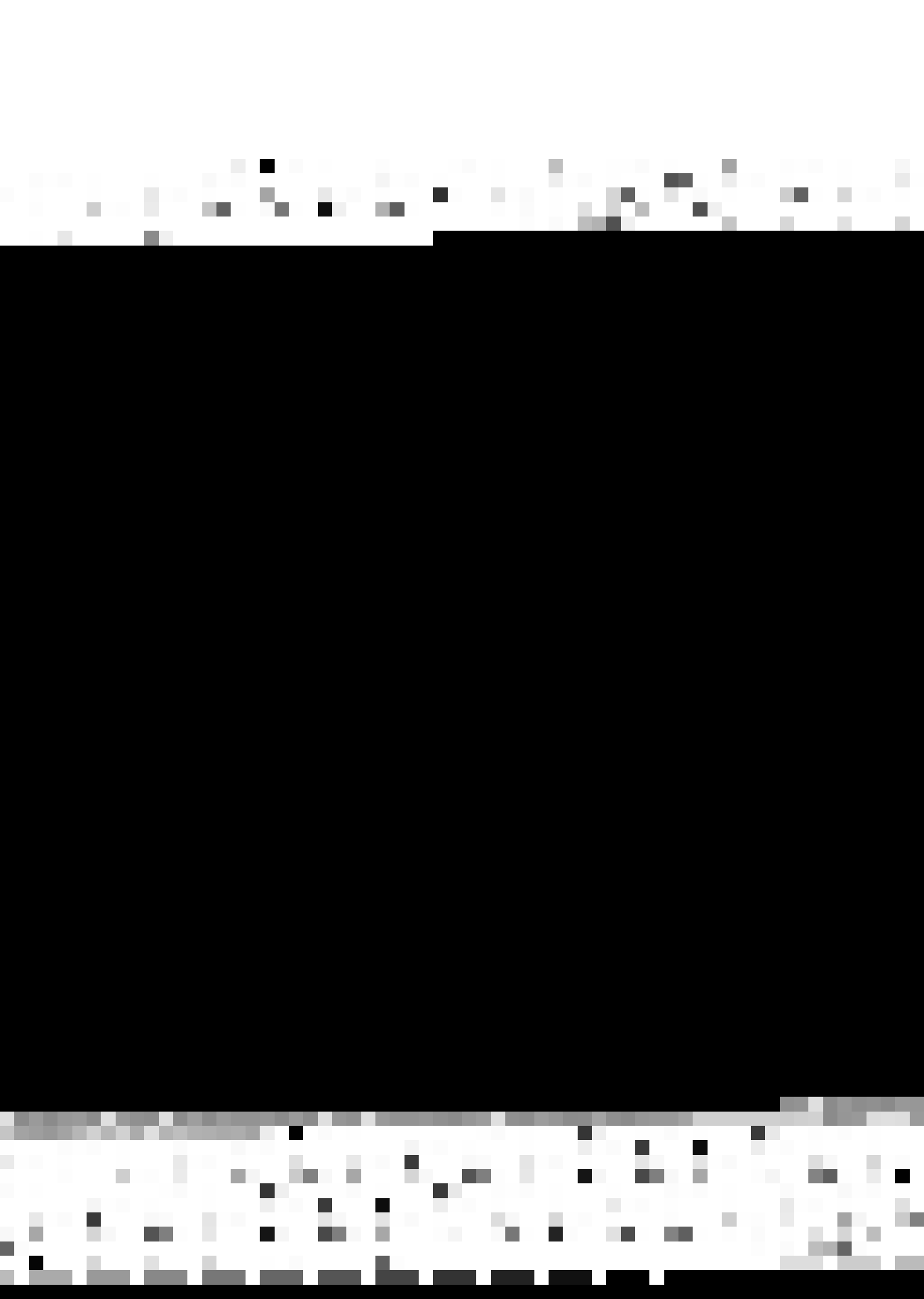
(a) 10 wt% Ti



(b) 15 wt% Ti



(c) 10 wt% Ti-4 wt% Ni



of the matrix is very high. It could be said that due to the high hardness of the matrix, it will give high grinding ratio and will perform free cutting constantly. This composite material will have better wear resistance, and will not easily allow the diamond particles to prematurely torn away from the matrix. Due to strong bonding between diamond and the matrix, diamonds will be pulled out only after completing their effective working life.

#### 4.3 CHARACTERISATION OF WEAR RESISTANCE

Wear resistance of various hot pressed and hot rolled metal matrix dispersed with diamond composite specimens were characterised by measuring the width of Flank wear land. The specimens of hot rolled and hot pressed were brazed to a mild steel plate and the whole assembly was fixed on a lathe machine.  $Al_2O_3$  tube was used as the work piece material and the cutting test was done for 15 and 30 min. Flank wear land was measured after each interval of 15 min and 30 min. Depth of cut was measured after 30 min by travelling microscope. The results are summarised in Table 4.11. The relationship between Flank wear and time is depicted in Fig 4.20 and Fig 4.21. Hot pressed D-B composite pellet has the minimum wear resistance or maximum Flank wear. Hot rolling improves the wear resistance as shown by the amount of Flank wear of rolled D-B and rolled D-B-4 wt% Ni. All the D-B-Ti composite tools show better wear resistance. From Fig 4.22, it can be seen that amount of Flank wear has the minimum value for 10 wt% Ti, which again increases for 15 wt% Ti. It can be inferred from the above observation that there is an optimum value of Ti, which gives maximum wear resistance or minimum Flank wear. Increase in Ti content, leads to the consumption of diamonds by the formation of  $TiC$ ,

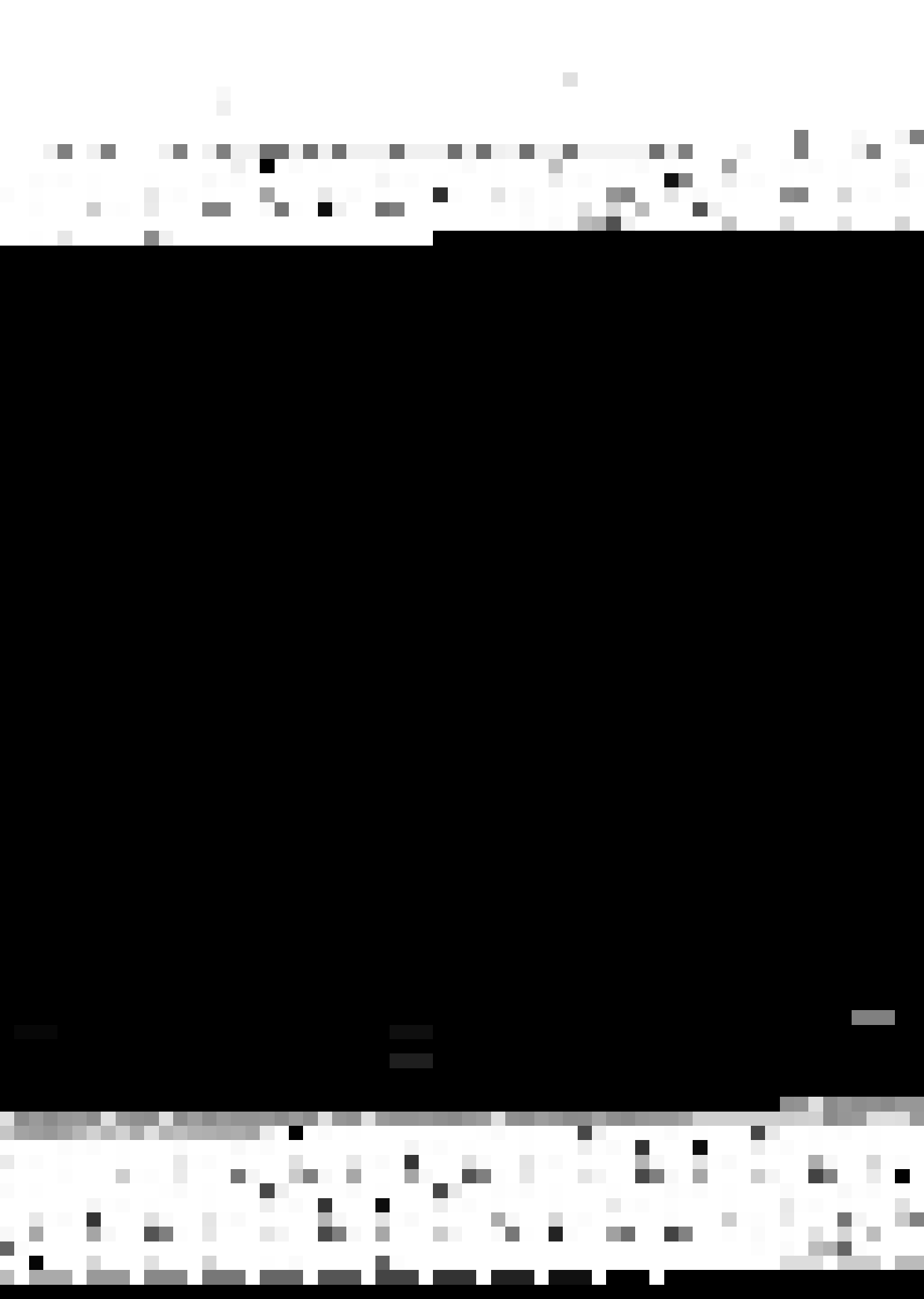


Table 4.11 Flank wear and Depth of cut of D-B composite material of various compositions.

Sample	Flank wear (mm)		Depth of cut after 30 min (mm)
	after 15 min	after 30 min	
H.P (DB)	0.32	0.41	0.05
H.P (DB + 4% Ni)	0.29	0.38	0.07
ROLLED (DB)	0.28	0.36	0.09
ROLLED (DB + 4% Ni)	0.22	0.30	0.13
H.P (DB + 5% Ti)	0.20	0.28	0.23
H.P (DB + 10% Ti)	0.15	0.22	0.33
H.P (DB + 15% Ti)	0.23	0.27	0.20
H.P(DB + 10% Ti + 4% Ni)	0.13	0.20	0.32

Table 4.12 Effect of Ti content on the Flank wear.

Amount of Ti in Diamond-Bronze (%)	Flank wear after 30 min (mm)
5	0.28
10	0.22
15	0.27



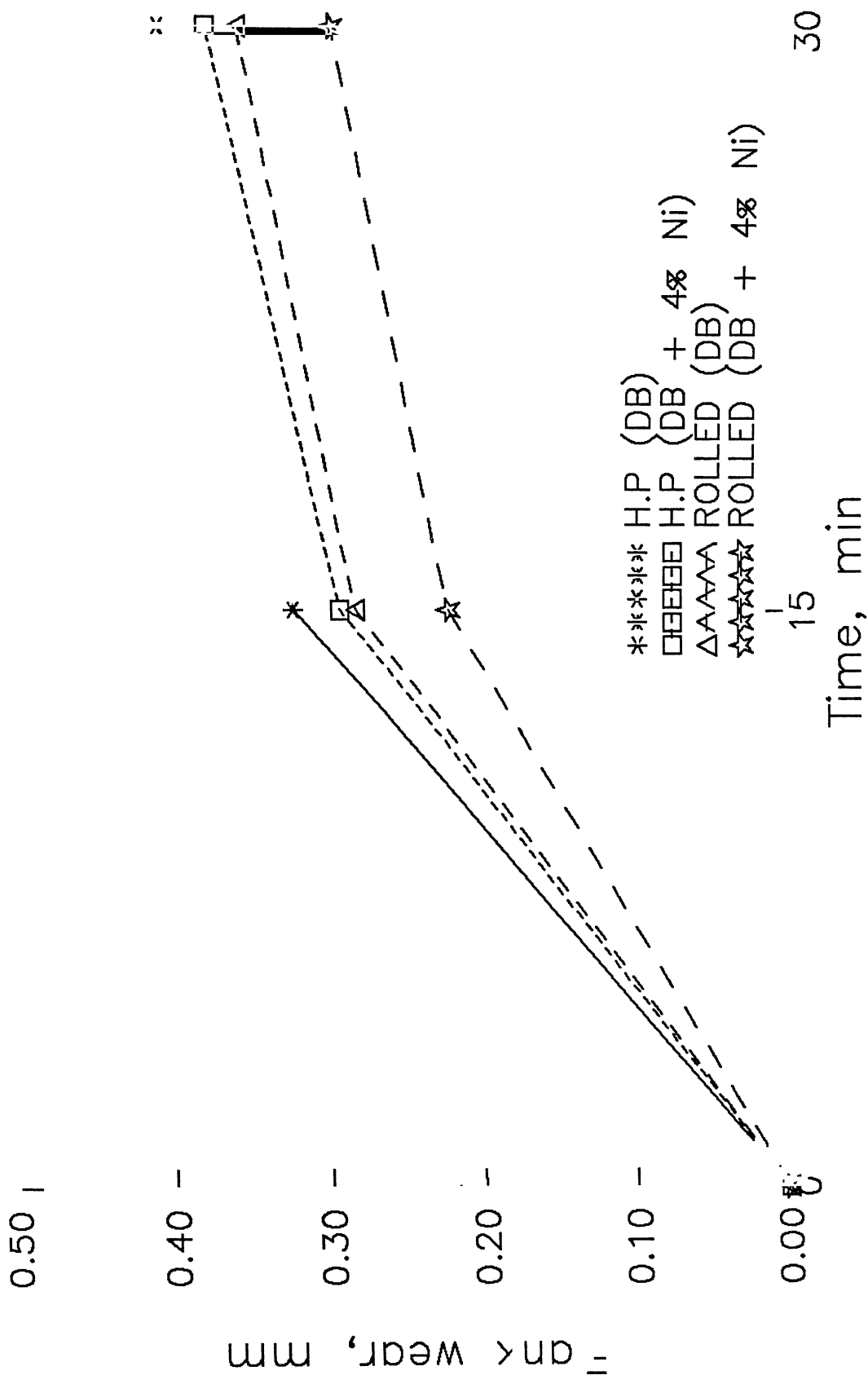
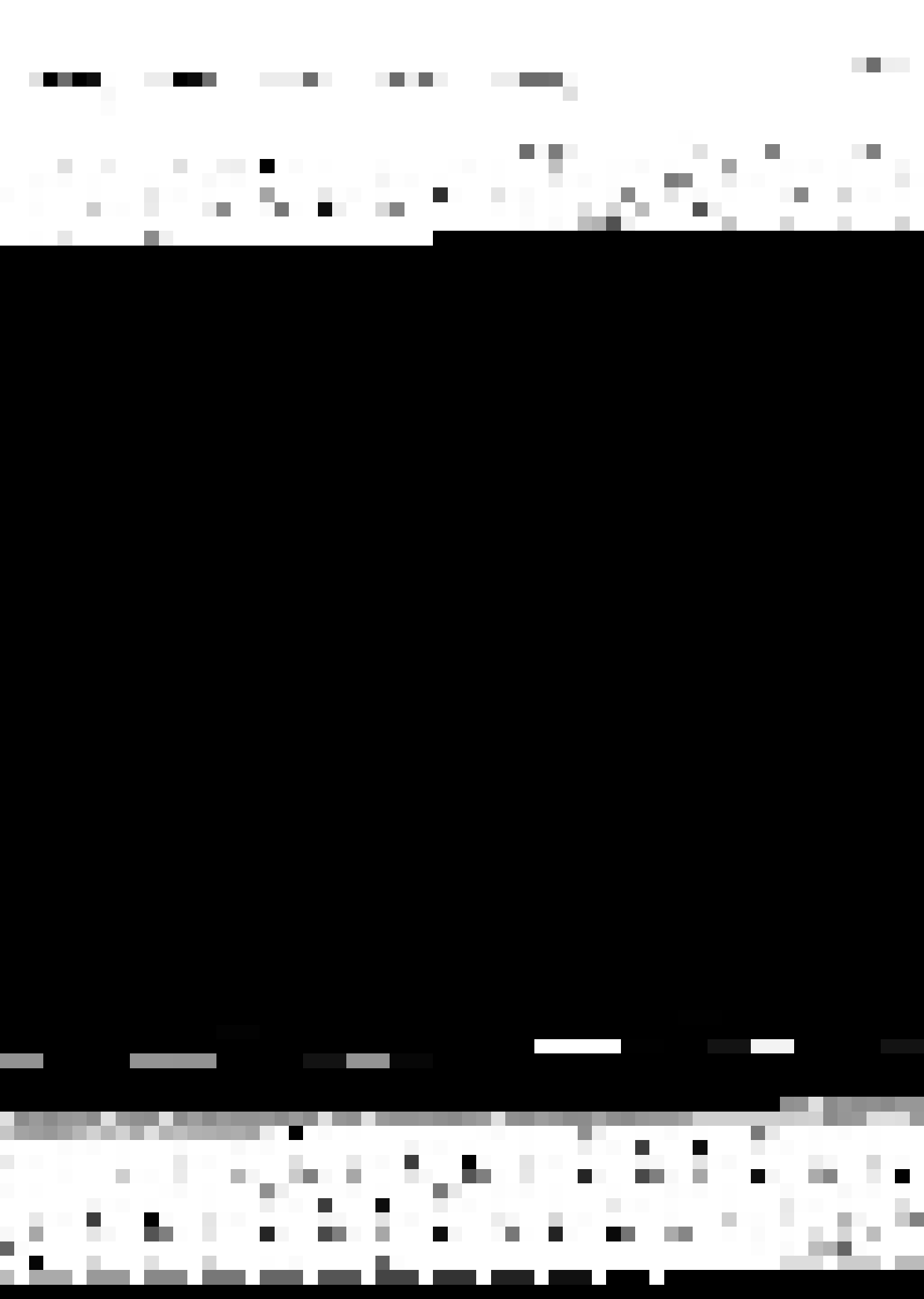


Fig 4.20 Flank wear Vs cutting time of hot pressed and hot rolled D-B and D-B-4 wt% Ni composite material





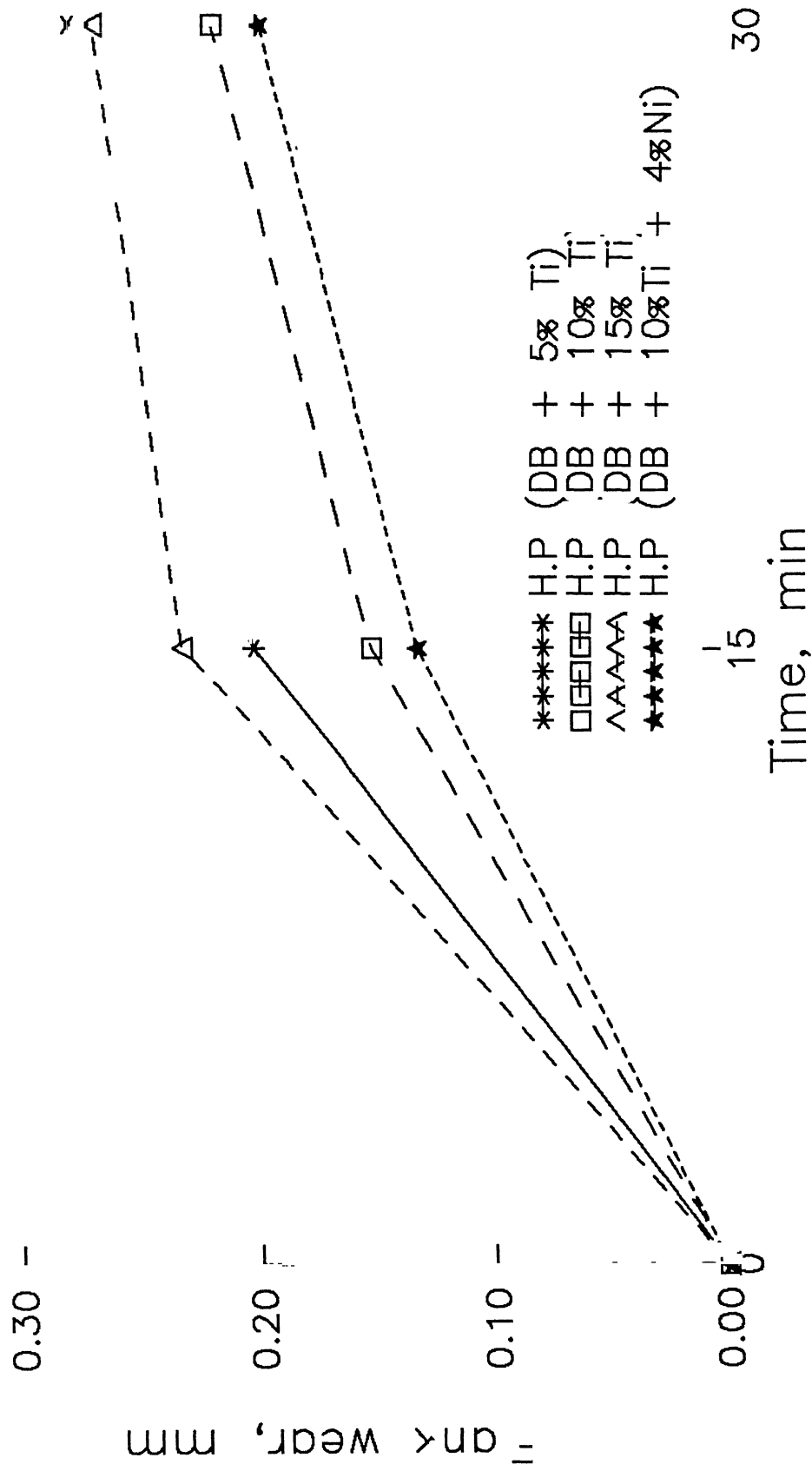


Fig 4.21 Flank wear Vs cutting time of hot pressed D-B-Ti-Ni composite material of various compositions



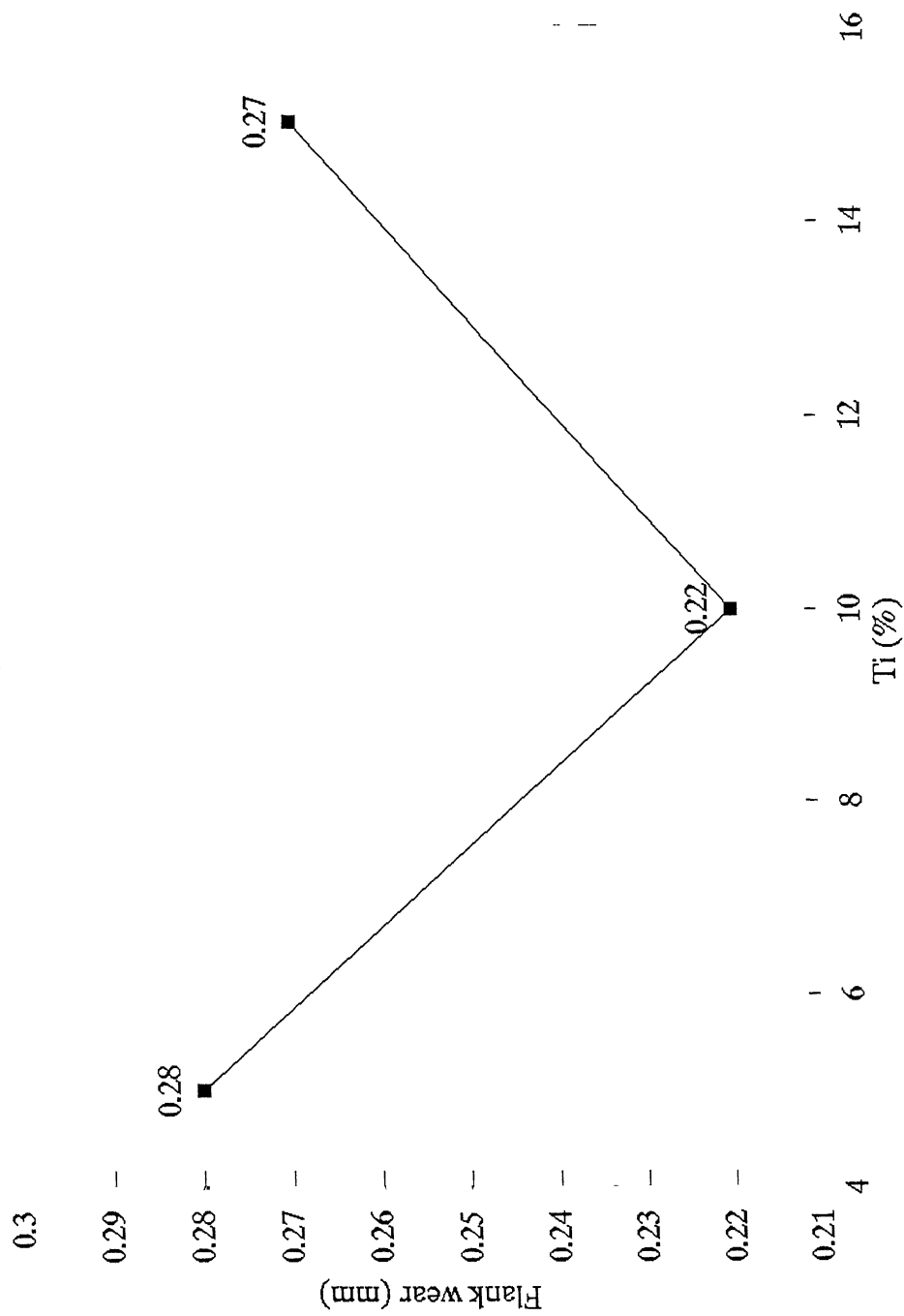
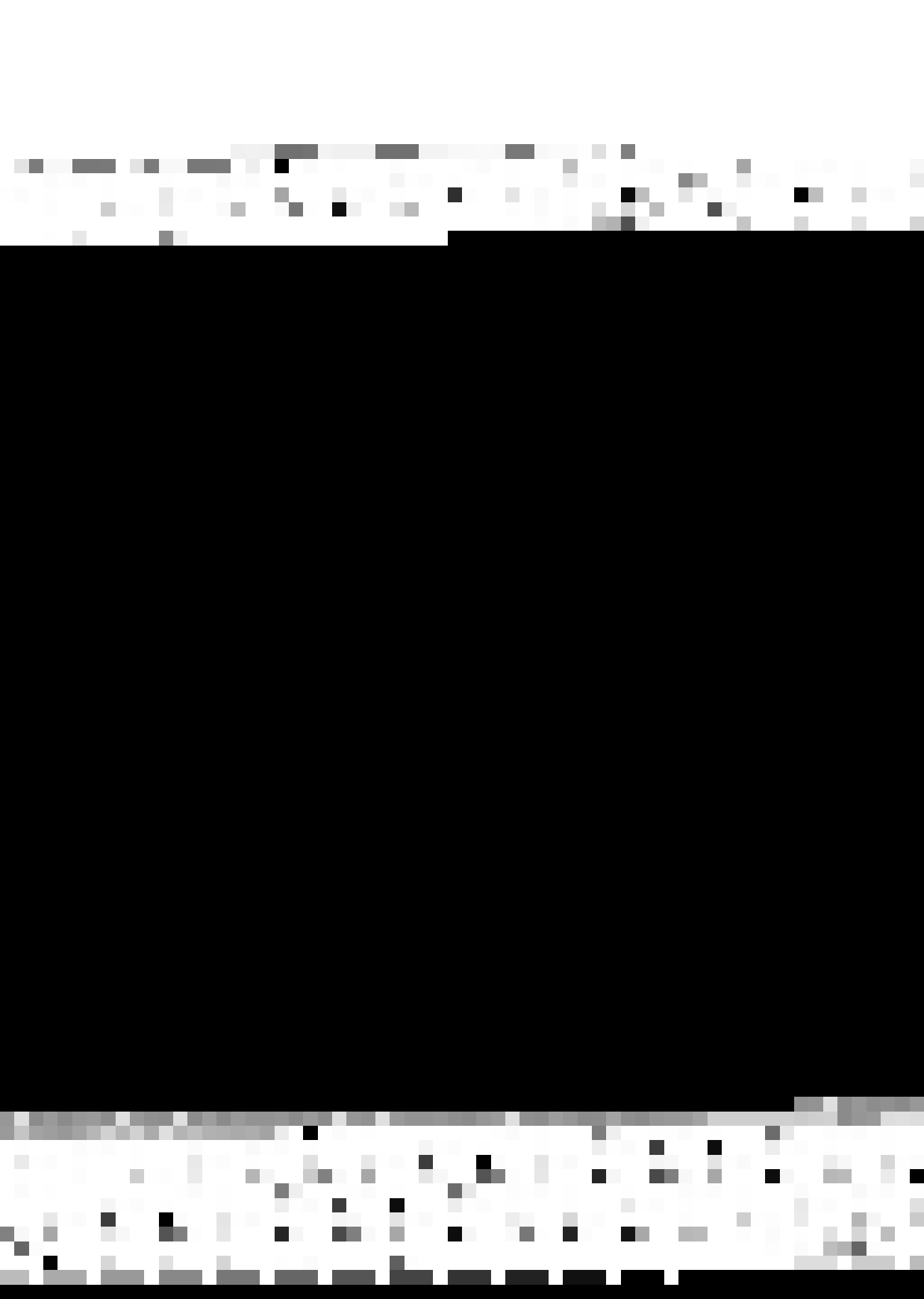


Fig 4.22 Effect of Ti content on Flank wear



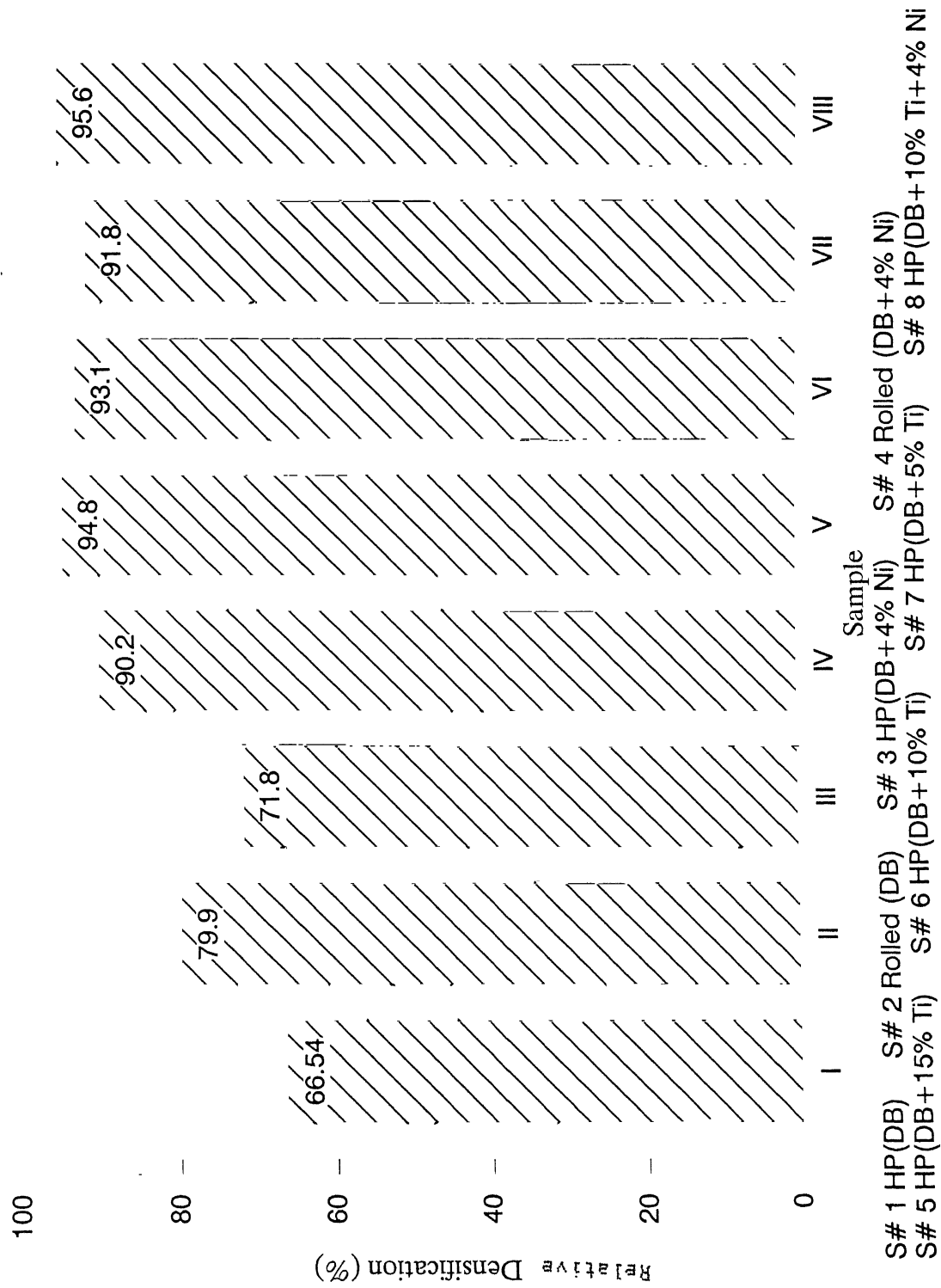
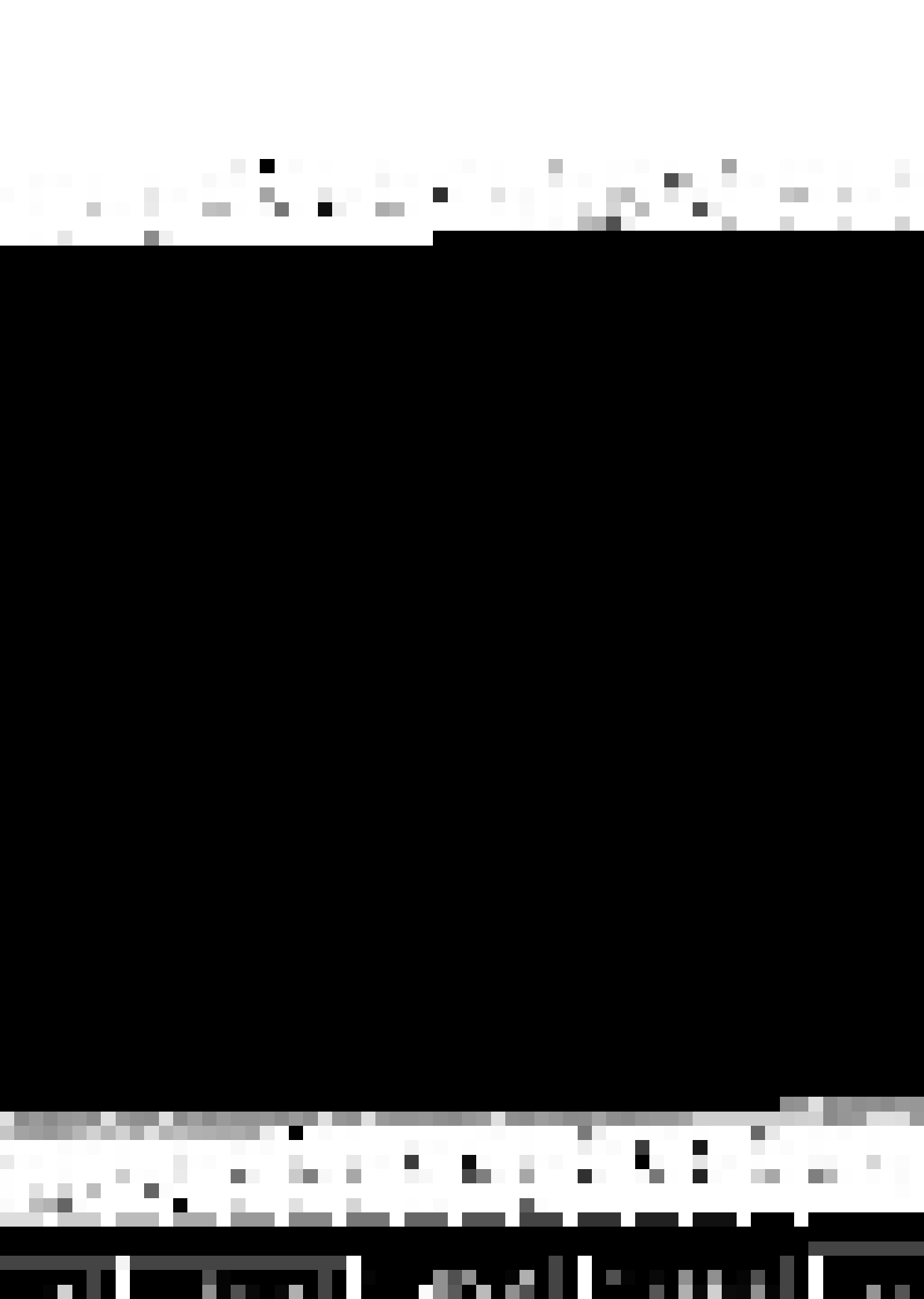


Fig 4.23 Densification behaviour of hot pressed and hot rolled samples of various compositions



which might be the reason in the decrease of wear resistance.

Maximum wear resistance shown by hot pressed D-B-10 wt% Ti-4 wt% Ni composite tool. When Ti and Ni both are added to the D-B composite mixture, complex intermetallic compounds are formed. These intermetallics impart higher hardness to the bond matrix. It holds diamond grits firmly preventing it to torn away prematurely. It can also be observed that there is a correlation between density and the wear behaviour of the composite tool. As the density increases or the porosity decreases, flank wear decreases. This is due to the fact that the pores present in the composite diamond tool reduces the adhesion of diamond to the matrix.

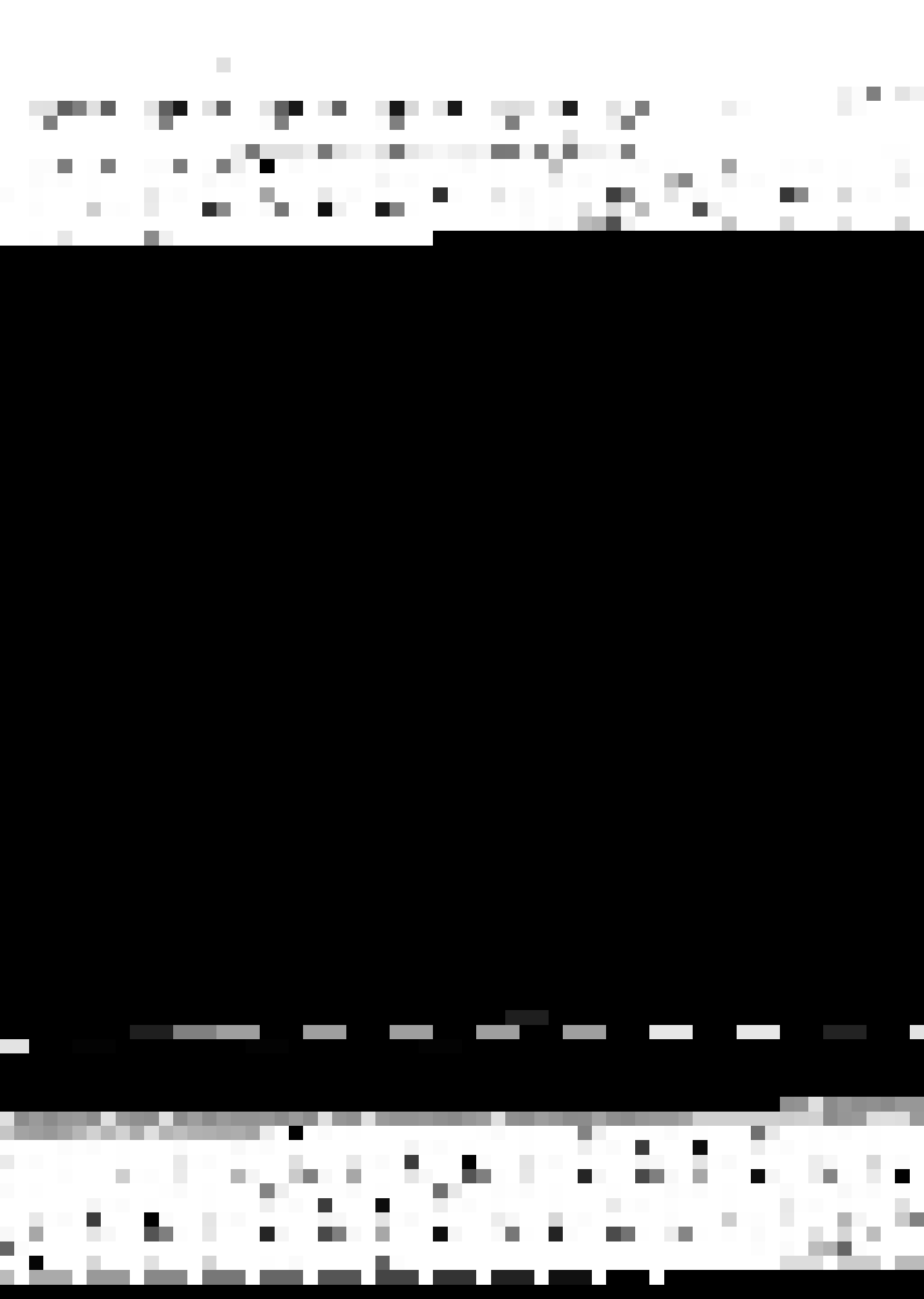
Fundamental improvements of the wear resistance of abrasive diamond tools can evidently expected from the addition of Ni and Ti. But these elements must fulfill one important requirement eg., strong adhesion of the diamond to the metal binder.





## CONCLUSIONS

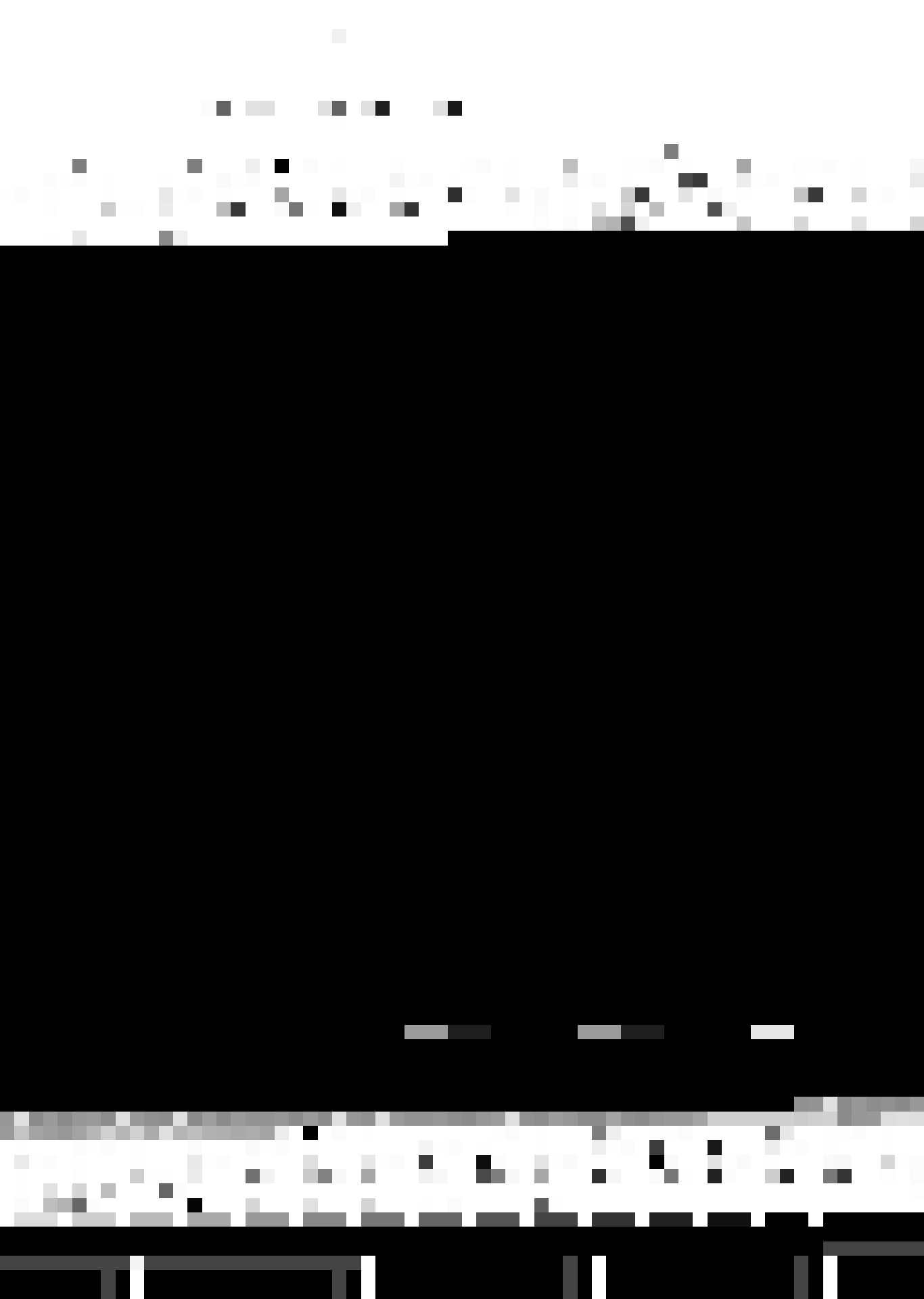
- 1) One of the most promising ways of improving the resistance of the diamond to wear is to raise the hardness of the binder. It could be done by rolling of the composite material.
- 2) Processing of D-B composite material by hot pressing and hot rolling was not very successful. Efficiency of Densification was less as a result of which composite strips lacked strength and wear resistance.
- 3) 4 wt% Ni, addition to D-B composite gives good strengthening through thermo-mechanical treatment. Addition of Ni increased the plasticity of the binder and hence the composite strips obtained after hot rolling had good interface strength. Thus it can be a reliable method for the manufacture of tools with a large working surface and a small thickness.
- 4) Cu-Sn-Ti, wets and bonds well with the diamond particles at temperature as low as 900°C. There is enhancement of Ti activity by Sn and the resultant production of metal rich, more wettable TiC reaction product layers at the alloy-carbon interface. This is reflected from the increased density and better wear resistance of the samples.
- 5) D-B composite material with Ti, has higher hardness value. Higher hardness of the matrix gives higher grinding ration and it is expected that the tool will perform free cutting constantly.
- 6) Porosity of the diamond tools must be very low. Porous strip reduces to a considerable extent, the adhesion of diamonds to the metal matrix. This is evident from the direct correlation between the density and the wear behaviour of composite tool samples. Hot pressed D-B-10-Ti-4-Ni, having 95.6% of theoretical density shows the least flank wear.



## CHAPTER 6

### SUGGESTIONS FOR FUTURE WORK

- 1) In the present investigation, wear resistance was characterised by measuring the Flank wear land after an interval of 15 min and 30 min. This can be extended for more time periods. Since sintered diamond tools have major application in the grinding of glass, the wear resistance could be characterised with respect to glass.
- 2) Since D-B-Ni composite material are precipitation hardenable materials, the effect of quenching and between passes on the strength properties should be analysed.
- 3) All sintered diamond compacts with Ti had densities greater than 90%. This could be given thickness reduction by hot rolling in Ar atmosphere. The deformation behaviour of these compacts will give interesting results. In the present case, coarse Ti powders were used. The effect of fine powder on the densification and wear behaviour should be investigated.



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